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Freshwater Invertebrate Monitoring;

2003-2007 analysis and evaluation

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Freshwater Invertebrate Monitoring;

2003–2007 analysis and evaluation

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Prepared for
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Contents

Executive Summary

The Auckland Regional Council (ARC) operates a freshwater ecology monitoring programme, primarily based on invertebrates, in rivers and streams throughout the Region. Objectives of this network include State of the Environment reporting, identification of major environmental issues and assessment of the efficacy and efficiency of Council policy initiatives and strategies. This report provides a "state" analysis of the monitoring network based on the data collected between 2003 and 2007.

Invertebrate samples and habitat assessments have been carried out annually at a range of sites stratified by land use around the region. The invertebrate samples were collected and processed according to the standard national protocols. The invertebrate data was interpreted using knowledge of the habitat requirements of different taxa and using a range of biological indices including taxonomic richness (total and EPT) and using the appropriate Macroinvertebrate Community Index (MCI) measures.

The highest scoring invertebrate communities were generally those from hard-bottom streams in catchments dominated by native forest. These communities tended to have high taxonomic richness, high numbers of EPT taxa and high MCI indices. The lowest scoring invertebrate communities were typically from streams in urban areas where poor physical habitat and water quality results in low numbers of taxa, few EPT taxa and low MCI indices.

The findings of this monitoring programme are comparable to those of similar national and regional programmes. The range and median for taxa richness and EPT richness reported here are very similar to those reported by national, Environment Waikato and Northland Regional Council monitoring programmes. The range of MCI scores reported by each of the programmes was also very similar, but the ARC programme reported a median MCI value on average 25 units greater than the other programmes. The reasons for this difference is not clear, but may be related to the relative proportions of high and poor quality sites in each programme.

It was concluded that the freshwater ecology monitoring programme has provided a large, valuable dataset for assessing the quality of Auckland streams based on the invertebrate community. The information provided by the programme has permitted an assessment of the "state" of selected streams in the Region. However, the relatively short nature of the data record (up to 5 years per site), prevents a robust assessment of "trends" at this time. Therefore, it is recommended that the current annual monitoring programme is continued to build further upon the existing valuable database by providing a sufficient data record to permit a robust trends analysis.

1 Introduction

1.1 The use of freshwater invertebrates in biological assessment

Many species of aquatic insects, crustaceans, molluscs, worms and other invertebrates (also known as “macroinvertebrates”) live in rivers and streams. These freshwater invertebrates have been used extensively for the biological assessment of aquatic ecosystems since the early 1900s (Metcalfe, 1989; Cairns & Pratt, 1993). Whilst other biological groups (such as fish, algae and plants) are used in some biological monitoring programmes, a clear preference for the use of invertebrates has emerged (Hellawell, 1977; Rosenberg & Resh, 1993). The ecology of invertebrates is well suited to this role as a biological assessment tool for the following reasons:

- Invertebrates are ubiquitous and abundant in most freshwater habitats
- Sampling procedures are well developed, relatively easy to apply and inexpensive
- Comprehensive keys are available allowing relatively easy identification
- Invertebrate communities are relatively heterogeneous (species rich) offering a spectrum of potential responses to environmental stresses
- Many invertebrates are relatively sedentary and are therefore representative of local conditions
- Many invertebrates have relatively long life cycles (commonly months to years) and consequently provide an integrated record of temporal changes in environmental quality.

As a result of a combination of these characteristics, invertebrates act as continuous indicators of the environment they inhabit. In contrast, other biological groups possess some, but not all, of these important attributes (Metcalfe, 1989).

Freshwater invertebrates are used by resource managers and environmental consultants as indicators in “state of environment” monitoring, consent compliance monitoring programmes and assessments of environmental effects (AEEs). Freshwater invertebrate assessment is a component of the “Stream Ecological Valuation” (SEV) method developed by the ARC (Rowe *et al.*, 2008) to score the ecological performance of Auckland streams in order to assist with AEEs and catchment management projects. Many Auckland community groups involved in the “WaiCare” programme monitor freshwater invertebrates in their local streams using methods designed for groups without professional freshwater biological experience (Jones *et al.*, 2007).

The complex taxonomic information that is generated from invertebrate samples is commonly summarised into indices. The use of indices aids communication of this complex information to non-experts and allows relatively quick comparisons among numerous sites and samples.

The most commonly used freshwater biological index used in New Zealand is the Macroinvertebrate Community Index (MCI) (Stark, 1985). Essentially, the MCI approach assigns a score to each animal found at a site based on its sensitivity to environmental stress; the overall MCI score for a site is based on the average score for all the animals found. This index and the others used in this report are explained further in the methods section.

1.2 ARC monitoring programme

The Auckland Regional Council (ARC) established the Freshwater Ecology Programme and began collecting invertebrate samples from streams in the region in 1999. The initial objective of the programme was to develop and standardise sample collection and processing methods. To that end, samples were collected repeatedly from 20 sites during 1999, 2000 and 2001. The results of this work supported the development of national protocols (Stark *et al.*, 2001) and were subsequently published in the scientific literature (Maxted *et al.*, 2003).

One of the key findings of Maxted *et al.* (2003) was the recognition that the MCI, which was originally developed for hard-bottom streams in the Taranaki Region, performed poorly in the soft-bottom streams commonly encountered in the Auckland Region. The MCI showed a restricted range in index scores between soft-bottom reference (pristine) sites and severely degraded sites compared with hard-bottom sites in similar condition. This constrained the ability of the index to define ecological conditions accurately in soft-bottom streams. Subsequently, effort was focused into developing a suitable index for the assessment of soft-bottom streams using invertebrate samples from the Auckland Region. This work utilised data from 179 samples from an expanded range of soft-bottom sites (41) collected between 2000 and 2005. The result was the development of the soft-bottom MCI (MCI-sb), which was initially reported in an ARC Technical Publication (Stark & Maxted, 2004) and subsequently in the scientific literature (Stark & Maxted, 2007a).

A brief ARC report (Maxted, 2005) summarised the findings from the 41 sites used to develop the MCI-sb index. The ecological state of the 41 sites, as measured using MCI-sb, was strongly correlated with catchment land use.

Following the development of the standard sampling protocols and MCI-sb index, the ARC entered a phase of data collection to identify the state and trends in the ecological health of the region's streams.

1.3 Programme objectives

The information generated by the Freshwater Ecology Programme, in conjunction with the ARC's other monitoring programmes, is used to meet the following objectives;

- Satisfy the ARC's obligations for state of the environment monitoring as required by section 35 of the Resource Management Act (1991).
- Contribute to community outcome monitoring required by the Local Government Act (2002).
- Help inform on the efficiency and efficacy of ARC's policy initiatives and strategies.

- Assist with the identification of large scale or cumulative impacts of contaminants and disturbance associated with varying land uses.
- Provide baseline, regionally representative data from which impacts of individual activities can be measured through compliance monitoring.
- Provide baseline, regionally representative data to support preparation of environmental effects assessments required through the resource consent process.
- Address queries from the public and promote awareness of freshwater issues.

A key issue for the region is to manage the effects of development on our natural environment. This includes balancing the needs for sustainable environmental management with the community's social, economic and cultural well being.

Specific objectives include managing and minimising the adverse effects of present and future urban and rural development, growth and intensification across the region. Invertebrate communities provide information on the condition of the region's streams and feedback on management actions. Such information is necessary to confirm that ARC's management strategies are effective in sustaining stream functions and uses. By achieving this outcome we are working towards achieving the ARC mission of "working in partnership with our regional community to achieve social, economic, cultural and environmental well being".

1.4 Report scope

Since 2003, the collection methodologies and processing procedures used by the ARC have been consistent. As a result, for each site up to five years data has been collected and is available for analysis; therefore it was considered timely for a progress report to align with the five year reporting framework for the other ARC monitoring programmes. This report presents an analysis of the state of the region's streams based on the invertebrate samples collected between 2003 and 2007.

2 Methods

2.1 Sample sites

This ARC monitoring programme has involved sampling at a total of 66 sampling sites since 2003. The number of sites sampled each year has varied due to logistical restrictions; for example 8 sites were sampled in 2003, whereas 63 were sampled in 2007 (Table 1). The location of each of the sites sampled between 2003 and 2007 is displayed below (Figure 1).

2.1.1 Monitoring network design

The sampling network began with 19 sites sampled between 1999 and 2001 with the primary objective of supporting the development of standard sampling methods. These sites were selected to capture the variation in invertebrate communities between hard-bottom and soft-bottom reference sites and soft-bottom sites of differing land-use impact (Maxted *et al.*, 2003). Of these sites, 13 have been retained in the current monitoring network (indicated by ❍ in Table 1).

Following the successful development of standard sampling methods (Stark *et al.*, 2001; Maxted *et al.*, 2003), the sampling network was subsequently expanded to facilitate the development of the soft-bottom MCI. Between 2000 and 2005, 50 soft-bottom sites were sampled (Stark & Maxted, 2007a) covering the range of major land use types found in the Auckland Region. Of these sites, 44 remain in the current monitoring network (indicated by ❑ in Table 1).

In addition, during 2001 and 2002 sites sampled as part of the rivers and streams water quality programme, that were not previously included in the network (and could be safely sampled using standard methods), were added to the invertebrate monitoring network to promote cross programme linkages. These 17 sites are denoted in Table 1 with the abbreviation LTB (long-term baseline) after the site name (see ARC 2007) for further information on these sites).

In 2003, 7 sites were included in the network for the first time; indeed, along with West Hoe LTB, these were the only sites sampled in this year. These sites were located around the Okura Estuary (Figure 1) and formed part of a wider network of freshwater and marine monitoring sites to assess the impact of land use intensification in the catchment (see ARC 2003 for further information). Of these sites, all have been retained in the current monitoring network (indicated by ♦ in Table 1).

It should be noted that some of the sites were included or retained in the monitoring network because they were appropriate for more than one of the above four purposes. In addition, during the development of the freshwater ecology programme, several sites have been removed, added or sampled intermittently without a documented explanation. Future changes in the network will be documented in an annual data report. More recently two sites have been added to monitor the effects of riparian restoration (Duder in 2006 and Motutapu in 2007), whilst the Dyers Creek sites (bush and paddock) were included in 2007 to support the Mahurangi Action Plan.

Table 1.

Sites sampled between 2003 and 2007, together with location details, land use, geology (soft or hard-bottom) and sample dates (ns = not sampled in that year). Symbols following site name indicate sites were included for sampling method development (❍), MCI-sb index development (❑) or Okura land use monitoring (♦). See Section 2.1.1 for further explanation.

Site ID	Site name	NZTM X	NZTM Y	Land use	Geology	2003	2004	2005	2006	2007
FWM004	Awarere (Dibble) ❑	1740623	5973867	forestry	soft	ns	25 Mar	01 Apr	13 Mar	23 Feb
FWM008	Riverhead ❑	1737125	5933216	forestry	soft	ns	ns	15 Mar	22 Mar	22 Feb
FWM009	Onepoto ❑	1754873	5925353	urban	soft	ns	ns	15 Mar	05 Apr	09 Feb
FWM010	Waiwhiu (Frith) ❑	1746500	5979619	forestry	soft	ns	25 Mar	08 Apr	13 Mar	23 Feb
FWM011	Puhinui (trib) ❑	1770102	5903276	urban	soft	ns	26 Feb	03 Mar	31 Mar	31 Jan
FWM012	Puhoi ❑ ❍	1744684	5960107	reference	soft	ns	10 Mar	09 Mar	19 Apr	08 Feb
FWM013	Oteha LTB ❑	1751903	5932876	urban	soft	ns	12 Mar	24 Mar	30 Mar	07 Feb
FWM014	Vaughan (upper) ❑ ❍	1754271	5938178	rural	soft	ns	17 Mar	10 Mar	30 Mar	20 Feb
FWM015	Puhinui (upper)	1770015	5903150	urban	hard	ns	26 Feb	03 Mar	31 Mar	31 Jan
FWM016	Chatswood ❑	1752860	5924026	urban	hard	ns	11 Mar	02 Mar	09 Mar	09 Feb
FWM018	St Pauls	1792352	5899343	forestry	hard	ns	23 Mar	17 Mar	06 Apr	01 Mar
FWM019	Orere B	1796917	5903677	forestry	hard	ns	23 Mar	21 Mar	21 Mar	07 Feb
FWM020	Orere A	1797276	5903177	forestry	hard	ns	23 Mar	21 Mar	21 Mar	07 Feb
FWM021	Kumeu LTB ❑	1739216	5928819	urban	soft	ns	17 Mar	14 Feb	15 Mar	22 Feb
FWM022	Hoteo (Kraak Hill) ❑	1743264	5974291	forestry	soft	ns	25 Mar	01 Apr	14 Mar	23 Feb
FWM023	Botany	1770333	5913019	urban	hard	ns	26 Mar	ns	ns	ns
FWM024	Symonds	1775578	5893744	rural	hard	ns	23 Mar	18 Feb	10 Mar	14 Feb
FWM028	Mahurangi LTB ❑	1747649	5964864	forestry	soft	ns	10 Mar	24 Feb	06 Mar	15 Feb
FWM031	Matakana LTB ❑	1753615	5976422	rural	soft	ns	10 Mar	24 Feb	28 Apr	15 Feb
FWM032	Wairoa LTB ❑	1782680	5901828	rural	soft	ns	19 Mar	18 Feb	24 Mar	19 Feb
FWM033	Papakura LTB ❑	1771066	5900274	urban	soft	ns	19 Mar	18 Feb	10 Mar	15 Feb
FWM034	Opanuku LTB	1742087	5915597	rural	hard	ns	17 Mar	23 Feb	03 Mar	01 Feb
FWM035	Oakley LTB ❑	1751914	5917503	urban	soft	ns	26 Mar	22 Feb	13 Apr	15 Feb
FWM036	Waiwera LTB ❑	1748575	5953652	rural	soft	ns	12 Mar	ns	ns	08 Feb
FWM037	Ngakaroa LTB ❑	1775165	5881618	rural	soft	ns	26 Mar	23 Feb	16 Mar	12 Feb
FWM038	Otara LTB ❑	1768326	5908371	urban	soft	ns	19 Mar	16 Mar	13 Apr	15 Feb
FWM039	Puhinui LTB ❑	1766445	5904298	urban	soft	ns	26 Feb	16 Mar	06 Apr	26 Feb
FWM040	Lucas LTB ❑	1751795	5934561	urban	soft	ns	24 Feb	21 Feb	01 Mar	07 Feb
FWM041	Vaughan (lower) LTB ❑ ❍	1755414	5938729	rural	soft	ns	15 Jan	21 Feb	01 Mar	20 Feb
FWM043	Milne ❍	1793286	5890536	reference	hard	ns	08 Mar	17 Mar	23 Mar	01 Mar
FWM044	Konini ❍	1795198	5895283	reference	hard	ns	08 Mar	17 Mar	23 Mar	01 Mar

FWM045	Mangatawhiri ❍	1793923	5897394	reference	hard	ns	08 Mar	17 Mar	23 Mar	01 Mar
FWM046	West Hoe LTB ❑ ❍ ♦	1748304	5950603	reference	soft	09 Apr	15 Mar	22 Feb	17 Mar	09 Feb
FWM047	Nukumea ❑ ❍	1749411	5951400	reference	soft	ns	15 Mar	22 Mar	17 Mar	27 Feb
FWM048	Cascade LTB ❍	1735633	5916371	reference	hard	ns	10 Feb	16 Mar	03 Mar	01 Feb
FWM049	Marawhara ❍	1730774	5910762	reference	hard	ns	03 Feb	15 Feb	15 Mar	05 Feb
FWM050	Wekatahi ❍	1731543	5910437	reference	hard	ns	03 Feb	15 Feb	15 Mar	05 Feb
FWM051	Shakespear ❑ ❍	1763934	5946824	rural	soft	ns	16 Mar	15 Mar	19 Apr	21 Feb
FWM052	Otanerua ❑	1749829	5952217	reference	soft	ns	16 Mar	22 Mar	ns	ns
FWM056	Mt Auckland ❑ ❍	1730852	5964294	reference	soft	ns	ns	29 Mar	ns	28 Feb
FWM057	Awanohi (upper 1) ❑ ♦	1750102	5936833	rural	soft	31 Mar	24 Feb	03 Feb	29 Mar	08 Feb
FWM058	Awanohi (upper 2) ❑ ♦	1750516	5937690	rural	soft	03 Apr	24 Mar	14 Feb	18 Apr	02 Feb
FWM059	Awanohi (trib) ❑ ♦	1750523	5937708	rural	soft	03 Apr	19 Mar	14 Feb	29 Mar	02 Feb
FWM060	Awanohi (mid) ❑ ♦	1750627	5937720	rural	soft	03 Apr	24 Mar	14 Feb	29 Mar	02 Feb
FWM061	Awanohi (lower) LTB ❑ ♦	1751424	5938711	rural	soft	08 Apr	24 Feb	21 Feb	18 Apr	20 Feb
FWM062	Okura (trib 1) ❑ ♦	1754059	5939002	rural	soft	08 Apr	05 Mar	03 Feb	ns	21 Feb
FWM063	Okura (trib 2) ❑ ♦	1752669	5938790	rural	soft	09 Apr	11 Mar	10 Mar	ns	08 Feb
FWM064	Campbells Bay ❑	1757043	5931334	urban	soft	ns	15 Jan	02 Mar	28 Feb	09 Feb
FWM065	Kauritutahi ❑	1741899	5893226	reference	soft	ns	25 Feb	04 Mar	02 Mar	22 Feb
FWM066	Waitakere	1733630	5918805	rural	hard	ns	10 Feb	15 Feb	22 Mar	05 Feb
FWM068	Aroara	1789897	5903472	rural	hard	ns	19 Mar	21 Mar	24 Mar	16 Feb
FWM069	Duder	1785588	5913500	rural	soft	ns	ns	ns	21 Mar	19 Feb
FWM070	Lignite ❑	1752340	5929258	rural	soft	ns	ns	24 Mar	09 Mar	14 Feb
FWM071	Eskdale (lower) ❑	1752441	5926765	urban	soft	ns	ns	30 Mar	07 Mar	05 Feb
FWM072	Eskdale (mid) ❑	1752739	5926517	urban	soft	ns	ns	30 Mar	07 Mar	05 Feb
FWM073	Eskdale (upper) ❑	1752993	5926470	urban	soft	ns	ns	30 Mar	07 Mar	05 Feb
FWM074	Mauku stream (STP) ❑	1760162	5882718	rural	soft	ns	ns	14 Apr	16 Mar	22 Feb
FWM075	Okura Reserve ❑	1753241	5940408	reference	soft	ns	ns	14 Apr	28 Apr	09 Feb
FWM076	Duck Creek ❑	1752605	5970451	rural	soft	ns	ns	09 Mar	ns	27 Feb
FWM078	Waiwhiu (Waiwhiu) ❑	1748405	5977107	reference	soft	ns	ns	01 Apr	ns	ns
FWM080	Ararimu	1734910	5932518	rural	soft	ns	ns	ns	ns	07 Mar
FWM081	Mauku (Aka Aka)	1764275	5877040	rural	soft	ns	ns	ns	ns	26 Feb
FWM084	Motutapu	1771846	5929049	rural	hard	ns	ns	ns	ns	02 Mar
FWM086	Kaukapakapa	1730776	5945155	reference	soft	ns	ns	ns	ns	07 Mar
FWM087	Dyers Creek (bush)	1751076	5963704	rural	Soft	ns	ns	ns	ns	13 Feb
FWM088	Dyers Creek (paddock)	1750910	5963846	rural	soft	ns	ns	ns	ns	13 Feb
					Number of sites sampled in year	8	48	56	52	63

Figure 1

The distribution of the 66 sampling sites used in the ARC freshwater invertebrate programme (2003-2007)

2.2 Sample collection/methodology

All samples were collected in late summer by trained ARC staff using the standard New Zealand protocols (Stark *et al.*, 2001). Hard-bottom streams were sampled using protocol C1, whereby a fixed area of stream bed is disturbed upstream of a hand held net. Soft-bottom streams were sampled using protocol C2, whereby a fixed area of stable substrate (woody debris, macrophyte or bank margins) is sampled by dislodging organisms into a hand held net. In streams with mixed substrata (hard bottom and soft bottom), the sampling method was determined by the dominant substrata.

The samples were preserved in the field and labeled appropriately for subsequent analysis.

2.3 Sample analysis

Sample analysis was undertaken by invertebrate taxonomists at the Cawthron Institute in Nelson in accordance with the standard New Zealand protocols (Stark *et al.*, 2001). Samples were processed using Protocol P1 and invertebrates were identified to the level required for the MCI (mostly genus or family level) using current New Zealand identification keys, particularly the aquatic insect keys in Winterbourn *et al.* (2006). Invertebrate taxa were placed into the semi-quantitative abundance categories:

- Rare (R)= 1 to 4 individuals
- Common (C) = 5 to 19 individuals
- Abundant (A) = 20 to 99 individuals
- Very abundant (VA) = 100 to 499 individuals
- Very, very abundant (VVA) = 500+ individuals

Specimens of all recorded taxa from each sample were preserved in ethanol allowing subsequent quality control checks. Each year, ten percent of the samples were subject to quality control checks using protocol QC1 (Stark *et al.*, 2001).

2.4 Data processing and analysis

Invertebrate data from each monitoring year was reported to the ARC in Excel spreadsheets which automatically calculated a range of biotic indices, including:

- Taxonomic richness (total number of taxa)
- Number of EPT taxa (Ephemeroptera = mayflies, Plecoptera = stoneflies and Trichoptera = caddisflies)
- %EPT taxa (percentage of the total number of taxa)
- MCI score (hard-bottom or soft-bottom as appropriate)

2.4.1 MCI indices

The rationale, development and the methodology required to calculate MCI indices is described in detail by Stark & Maxted (2007b). Briefly, the MCI system assigns a tolerance value of between 1 and 10 to each of the taxa found in freshwater invertebrate samples. The tolerance value for each taxon is based on that taxon's perceived sensitivity to environmental stress; a value of 10 is indicative of highly sensitive taxa, whereas a value of 1 is indicative of highly tolerant taxa. The overall MCI score for a sample is calculated as the mean of the tolerance values for all the taxa in present in the sample multiplied by 20. Therefore the theoretical range of MCI scores is 0 (where no invertebrates are found in a sample) to 200 (where all invertebrates found in a sample have a tolerance value of 10). These extreme scores are highly unlikely, and in practice it is uncommon to find MCI scores of greater than 150 or lower than 40 (Stark & Maxted, 2007b). For example, the MCI scores in this report range from 27 to 157, but most scores fell between 80 and 150 (Section 3.2.2).

The MCI system was originally designed to measure the effects of nutrient enrichment on stony stream invertebrate communities (Stark 1985). It was proposed that certain ranges of MCI values were indicative of certain levels of pollution (values above 119 indicating pristine conditions, 100 to 119 indicating mild pollution, 80-99 indicating moderate pollution and below 80 indicating gross pollution) and such criteria are still regularly quoted. However, these pollution criteria should be used with caution because MCI (and MCI-sb) values are not determined solely by pollution. Many stream habitats support invertebrate communities with low MCI values because of reasons other than pollution. Sensitive (high scoring) taxa that produce high MCI values may be replaced by tolerant (low scoring) taxa because of:

- a reduction in current speed (riffles support more high-scoring taxa than pools)
- an increase in stream temperature (sensitive taxa generally require cool waters)
- a decrease in dissolved oxygen levels (sensitive taxa generally require high DO levels)
- smothering of the streambed by fine sediment (many sensitive taxa require stony substrata)
- a reduction in quality of riparian vegetation (tree cover may be required by the adults of some sensitive taxa and terrestrial vegetation provides the main food source for many taxa)
- a lack of recruitment by sensitive taxa (e.g. the upstream reaches may be impounded, piped or concrete-lined) or
- tidal influence (few sensitive taxa are found in tidally affected streams).

Therefore the MCI indices are now more appropriately considered a measure of general water and habitat quality rather than a measure of nutrient enrichment. As such, the interpretation of MCI values was reassessed and a quality classification described (>119 = excellent; 100-119 = good; 80-99 = fair; <80 = poor) that recognises the MCI responds to an interacting complex of environmental variables (Stark & Maxted, 2007b).

An updated version of the MCI-sb was published in 2007 (Stark & Maxted, 2007a) which refined the tolerance values for many of the scoring taxa. Hence, to ensure consistency within this and with other reports, these updated tolerance values were used to recalculate the MCI-sb for all soft-bottom samples used for this report.

2.5 Habitat Quality Assessment

Assessments of habitat quality have been carried out at each site concurrently with invertebrate sampling. The ARC developed a scoring system for assessing habitat quality based on methods used by the USEPA. The system scores the seven measures of habitat quality described below on a scale of 0 to 20, giving a potential range of 0 to 140. The measures of habitat quality relate to:

- Aquatic habitat abundance; based on the proportion of stream channel favourable for epifauna colonisation.
- Aquatic habitat heterogeneity; based on the diversity of aquatic habitats.
- Hydrologic heterogeneity; based on the diversity of hydrologic conditions.
- Channel alteration; based on the extent of human-modified channel.
- Bank stability; based on the proportion of banks showing evidence of erosion.
- Channel shading; based on the proportion of channel shaded by vegetation.
- Riparian vegetation integrity; based on the extent of human modification to the riparian zone.

A copy of the field sheet giving full descriptions of the scoring criteria for each measure is presented as Appendix 1.

Habitat quality data recorded from each sampling site were analysed by land use and compared with the invertebrate data to investigate relationships between biotic indices and habitat quality.

2.6 Statistical analysis

This monitoring programme has provided a large amount of data from sampling sites that can be grouped into different site categories (or populations), particularly the different land uses (native bush, exotic forest, rural and urban areas) and different bed types (hard bottom and soft bottom). Much of the statistical analysis used in this project involved comparisons between the means (mean numbers of taxa, MCI values, EPT values etc) from these groups of sites.

When the means from different groups of sites are found to be different, the question becomes "how likely is it that the differing means are just the chance result of random sampling?" (i.e. there is no real difference between the means from different populations). Similarly where changes in one variable affect another the two will be correlated and their relationship may be described by a regression line. In this case the above question becomes "how likely is it that the difference between zero and the calculated slope is just the result of random sampling".

P-values (based on a "maximum likelihood ratio test") provide a measure of the evidence that an observed difference (e.g. a difference between the means of two types of sites, or the difference between a correlation and zero) results from a real, underlying effect rather than sampling variability. A p-value is the probability that a difference as large as (or larger than) that observed could occur by chance even if there were no real underlying difference. Like all probabilities it is a number between 0 and 1. For example, a P-value of 0.05 indicates there is a 5% chance of observing a difference as large as that observed even if the two underlying population means are identical. In other words random sampling from identical populations would lead to a difference smaller than that observed in 95% of surveys and larger than that observed in 5% of surveys. The value 0.05 is conventionally taken as reasonable evidence of a real difference. A P-value smaller than 0.001 indicates very strong evidence of a real difference and a P-value greater than 0.1 indicates there is little evidence of real difference.

Statistical analysis was performed with linear mixed effect ("lme") models (Pinheiro *et al*., 2008) as implemented in the statistical programming language "R" (R Development Core Team, 2006). These models separate the variability of sites from the variability within sites, and then use the correct mix of variances in estimates of the standard errors of differences and other model parameters. P-values were based on likelihood ratio tests comparing different models.

Variability within sites was not constant, and estimating different weights for each land use was the most satisfactory way of correcting for this overall. Factors such as land use, bottom type and linear trend over time, were fitted in a full factorial pattern, which was reduced to a model that minimised "Akaike Information Criterion" (AIC) (Hirotugu, 1974) and satisfied marginality constrains. The AIC is a measure of how well a model summarises the information in the data, balancing the number of parameters against its goodness of fit.

Another analysis, the Spearman rank correlation co-efficient, was used to assess the relationship between MCI score and water quality. This technique is a non-parametric measure of correlation and it assesses how a simple monotonic function can describe the relationship between two variables, without making any assumptions about the frequency distribution of the variables as required by similar parametric tests (Legendre & Legendre, 1998).

3 Results

3.1 Auckland Region stream invertebrate community composition

The composition of invertebrate communities, particularly the numbers of taxa in certain taxonomic groups (e.g. mayflies) and the abundances of particular taxa, provides useful information about the state of the stream biota and its habitat. Different taxa have different habitat and water quality requirements, and knowledge of the basic natural history and habitat requirements of these taxa forms the basis of biotic indices such as the MCI.

Some invertebrate taxa are generalists, capable of surviving in a wide range of habitat and water quality conditions. Such taxa are among those most frequently recorded in the ARC regional monitoring programme (Figures 2 to 5). For example, *Potamopyrgus* snails were recorded at most sampling sites and *Zephlebia* mayflies were common at sites where native vegetation provided cover.

3.1.1 Hard-bottom sites

Many taxa were more commonly recorded in hard-bottom sites (Figures 2 and 3) than in soft-bottom sites, in particular;

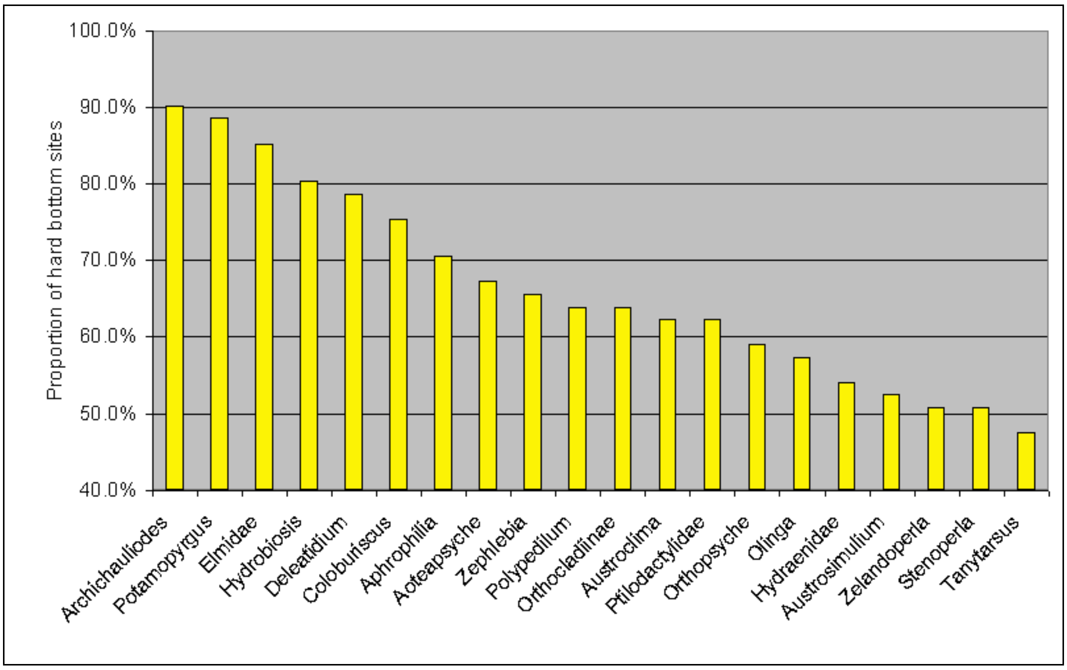
- biofilm grazers, including orthoclad and *Tanytarsus* midges, *Deleatidium* (Figure 2) and *Austroclima* mayflies, and *Latia* limpets (Figure 2),
- filter feeders that hold on to stony surfaces in flowing waters, including *Coloburiscus* mayflies (Figure 2), *Aoteapsyche* and *Orthopsyche* caddisflies, and *Austrosimulium* blackflies,
- burrowers that inhabit stony stream beds, including elmid beetles and *Aphrophila* craneflies, and
- predators of other stony stream invertebrates, including *Archichauliodes* dobsonflies and *Hydrobiosis* caddisflies.

Figure 2.

Examples of invertebrates utilising hard bed material at various stages of the life cycle. Top row; *Latia* limpet eggmass (left) and adult grazing on stone surfaces (right). Second row; *Coloburiscus* mayfly holding onto stone while filter feeding (left) and *Deleatidium* mayfly showing mouthparts adapted to scrape algae from stone surfaces (right). Third row; bryozoan colony attached to stone (left) and midge tubes attached to stone (right). Bottom row; caddis pupae attached to stone surfaces (left, *Hydrobiosis*; right, *Pycnocentrodes*).

Figure 3.

Taxa recorded most frequently at hard-bottom sites in the ARC freshwater invertebrate programme during 2003-07.



3.1.2 Soft-bottom sites

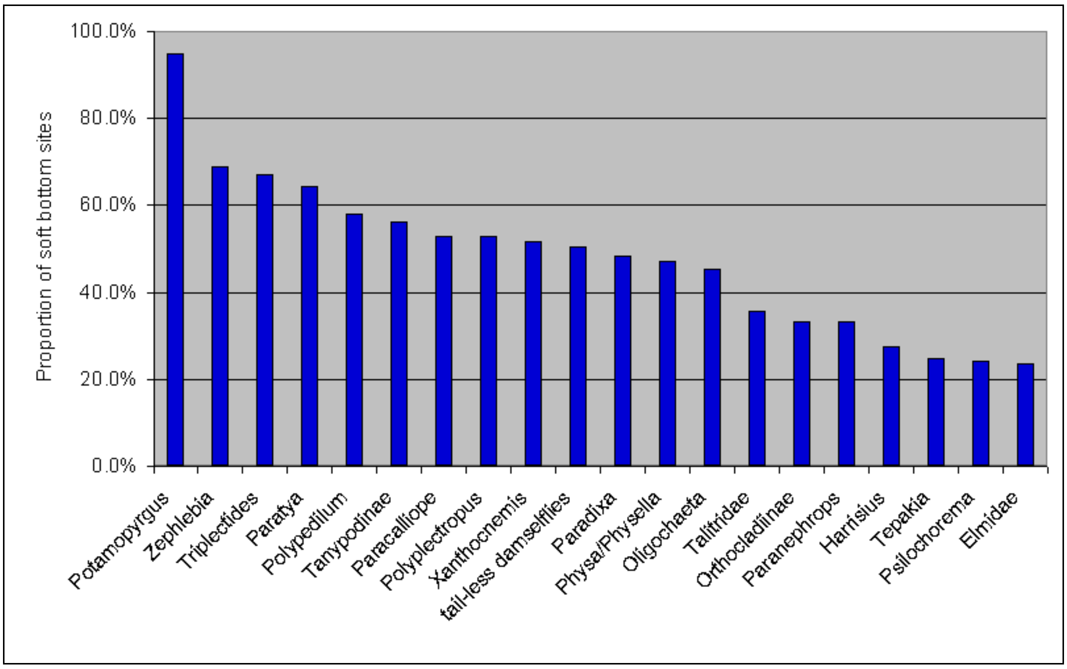
A high proportion of ARC sampling sites are dominated by soft sediment substrata, with typically slower flow than most hard-bottom sites. Slow flow is often the result of the small, low gradient catchments typical of the Auckland Region, and allows fine sediment to settle out of suspension, hence the frequently encountered sandy or muddy substrata. Taxa found in a higher proportion of soft-bottom habitats (Figures 4 and 5) than in hard-bottom habitats included:

- swimming crustacea, particularly the *Paracalliope* and talitrid amphipods (Figure 4), and *Paratya* shrimps,
- slow-water specialists, particularly *Xanthocnemis* damselflies, *Paradixa*, *Polypedilum* and tanypod midges, Physidae snails, oligochaete worms, and *Paranephrops* crayfish (Figure 4),
- inhabitants of woody debris (often targeted when sampling soft-bottom habitats) including *Triplectides* caddisflies and *Harrisius* midges (Figure 4), and
- filter feeding *Polyplectropus* caddisflies that spin nets to catch food particles drifting in slow-flowing waters.

Figure 4.

Examples of invertebrates recorded more commonly in soft-bottom sites than hard-bottom sites. Top row; talitrid amphipod (left), and *Paranephrops* crayfish (right). Middle row; Physidae snails (left) and *Xanthocnemis* damselfly (right). Bottom row; *Paradixa* midge (left) and *Harrissius* midge (right).

Figure 5.
Taxa recorded most frequently at soft-bottom sites in the ARC freshwater invertebrate programme during 2003-07.



3.1.3 All sites

The most frequently occurring taxa in the Auckland Region monitoring programme (Figure 6) are also among the most commonly recorded taxa at the National Rivers Water Quality Network (NRWQN) sites located throughout New Zealand (Boothroyd, 2000). However, the nature of the Auckland Region, with generally low altitude, low gradient catchments drained by small streams of short length (from headwaters to the sea) affects the frequency of occurrence of some invertebrate taxa. The close proximity of most ARC sampling sites to the sea increases the frequency of occurrence of migratory *Paratya* shrimps. The low gradient landscape typically results in slow current speeds and soft-bottom pool or run habitats that are less suitable for riffle-dwelling taxa (many EPT taxa) and more suitable for slow-water specialists such as *Potamopyrgus* snails, *Zephlebia* mayflies, amphipods and *Polyplectropus* caddisflies.

Figure 6.

Most frequently recorded invertebrate taxa in the ARC monitoring programme during 2003 to 2007, in order of abundance. Top row; *Potamopyrgus* snail (left) and *Zephlebia* mayfly (right). Second row; *Polypedilum* midge (left) and *Paratya* shrimp (right). Third row; *Triplectides* caddisfly (left) and tanypod midge (right). Bottom row; oligochaete worm (left) and *Paracalliope* amphipod (right).

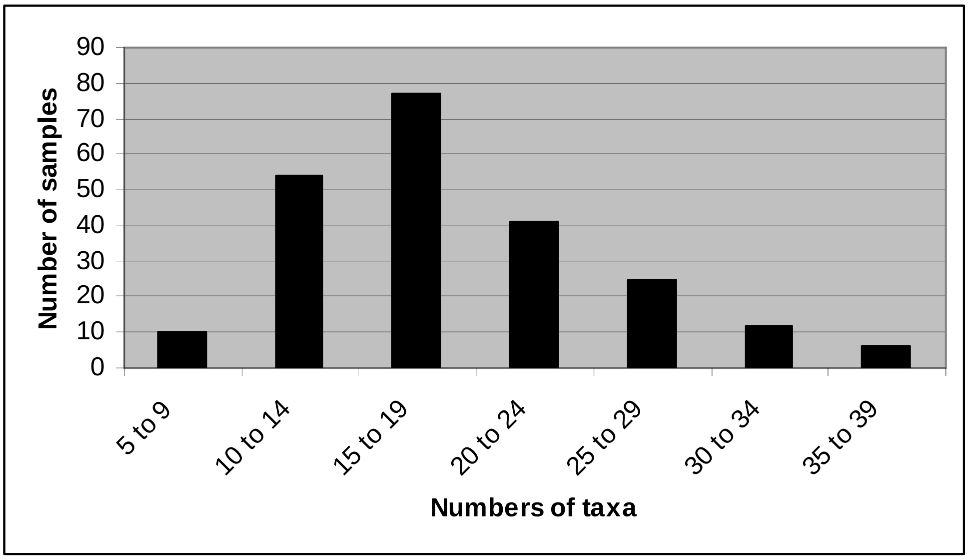
3.2 Biotic indices from Auckland Region streams

Freshwater invertebrate data are often simplified by biotic indices into numerical values representing particular aspects of community composition. The main biotic indices used by the ARC are discussed in the following sections.

3.2.1 Invertebrate taxonomic richness frequency distribution

The numbers of taxa recorded per sample during the ARC monitoring programme ranged from 5 to 37, with a median of 18 taxa. State of the Environment monitoring in the neighboring Waikato Region in 2006 recorded 4 to 32 taxa, with a median of 18 taxa (Kevin Collier (Environment Waikato), pers. comm.). State of the Environment monitoring in the neighboring Northland Region in 2007 recorded 4 to 28 taxa, with a median of 15 taxa (Pohe & Hall, 2007). The ARC findings are also similar to those recorded by Scarsbrook *et al.* (2000) who reported a range of 3 to 34 taxa and a median of 18 taxa from 66 of the NRWQN sites. The taxonomic richness frequency distribution chart (Figure 7) shows the vast majority of ARC samples contained between 10 and 24 taxa. These results are similar to those from elsewhere in New Zealand; relatively few samples contain fewer than 10, or more than 30 taxa.

Figure 7.
Frequency distribution of numbers of taxa recorded during the ARC freshwater invertebrate programme 2003-07.



Samples containing high numbers of taxa (e.g. more than 30) were usually collected from high quality stream sites, particularly those draining forest-covered catchments, with permanent flow, cool water, high dissolved oxygen levels, and stable stony or woody substrata. Samples containing fewer than 10 taxa typically originated from urban or rural sites with poor water quality (e.g. low dissolved oxygen levels or warm temperatures) or poor habitat quality (e.g. unstable muddy substrata or lack of permanent flow).

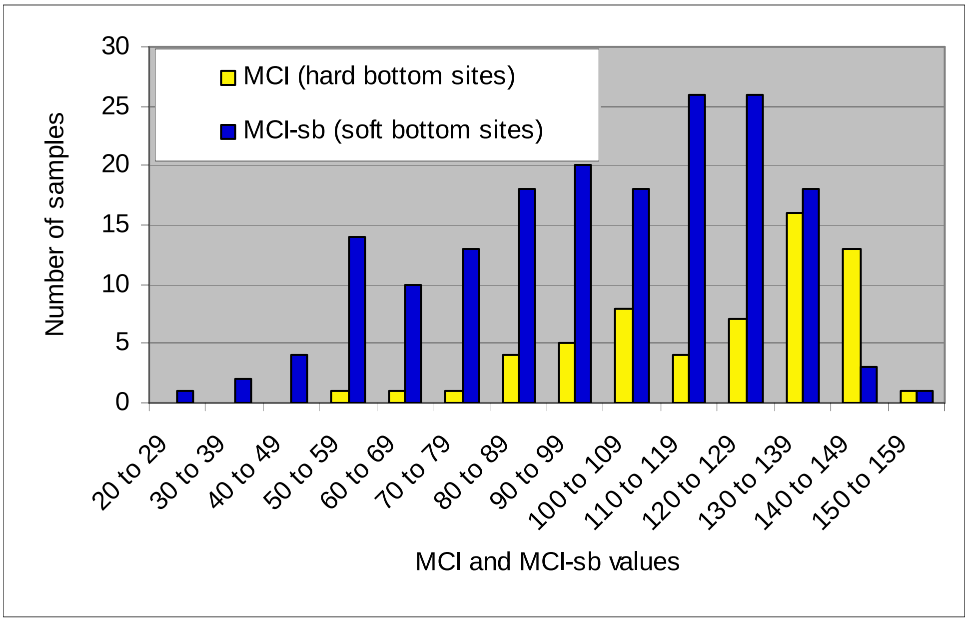
3.2.2 MCI metrics frequency distribution

The MCI values recorded per sample from hard-bottom sites during the ARC monitoring programme ranged from 55 to 151, with a median of 128. State of environment sampling in the neighboring Waikato Region in 2006 recorded MCI values ranging from 60 to 164.8, with a median of 108.4 (Kevin Collier (Environment Waikato), pers. comm.). State of the Environment sampling in the neighboring Northland Region in 2007 recorded MCI values ranging from 68.3 to 129.5, with a median of 96.4 (Pohe & Hall, 2007). Scarsbrook *et al.* (2000) reported MCI values between 44 and 145 (median 103) from a survey of 66 of the NRWQN sites.

The MCI and MCI-sb frequency distribution chart (Figure 8) shows most MCI values fell between 100 and 150, while there was a wider spread of MCI-sb values, with most values between 80 and 140. The MCI and MCI-sb results can be difficult to compare with those from other programmes or regions, because the range of index values in any programme is determined by the selection of sites in relation to catchment position and land use, and the selection criteria may vary between different regional councils.

Samples producing high MCI or MCI-sb values (e.g. more than 120) were typically collected from high quality stream sites, particularly those draining bush/forest covered catchments with permanent flow, cool water, high dissolved oxygen levels, and stable stony or woody substrata. Samples with MCI or MCI-sb values below 80 tended to originate from urban sites (see section 3.9.2).

Figure 8.
Frequency distribution of MCI values (hard-bottom sites in yellow) and MCI-sb values (soft-bottom sites in blue) recorded during the ARC freshwater invertebrate programme 2003-07.



3.2.3 Numbers of EPT taxa and %EPT frequency distributions

Many EPT taxa are found most commonly in permanently flowing, stony streams, and most require high levels of dissolved oxygen and cool water temperatures. Such habitat conditions are most likely to occur in areas of native or exotic forest, and therefore high numbers of EPT taxa are often associated with forest covered catchments. Stony substrata are particularly important for many EPT taxa for a range of reasons including:

- some feed by grazing biofilms from hard surfaces,
- some require hard surfaces for attachment sites during egg laying or pupation,
- some require stable attachment sites while filtering food from the current,
- some are predators of other stony stream invertebrates, and
- most require the shelter provided by stable stones or boulders during flood events.

Soft-bottom sites, particularly those in developed (farmland or urban) catchments therefore tend to support fewer EPT taxa than hard-bottom sites in undeveloped catchments.

The numbers of EPT taxa recorded per sample during the ARC monitoring programme ranged from 0 to 23 (Figure 9), with a median of 6. State of the Environment monitoring in the neighboring Waikato Region in 2006 recorded 0 to 23 EPT taxa, with a median of 8 (Kevin Collier (Environment Waikato), pers. comm.). State of the Environment monitoring in the neighboring Northland Region in 2007 recorded 0 to 15 EPT taxa , with a median of 5 (Pohe & Hall, 2007). Scarsbrook *et al*. (2000) reported 0 to 18 EPT taxa (median 8) in a survey of 66 of the NRWQN sites.

The EPT frequency distribution chart (Figure 9) shows the vast majority of ARC samples contain fewer than 9 EPT taxa. Most of the ARC samples containing 10 or more EPT taxa were from hard-bottom, well-shaded streams (usually under native or exotic forest).

Samples containing no EPT taxa, or only the tolerant hydroptilid caddisflies (*Oxyethira* or *Paroxyethira*) often reflect poor water quality (e.g. nutrient-enriched sites with low dissolved oxygen levels or warm temperatures) or poor habitat quality (e.g. unshaded sites with weedy or algae-covered substrata).

In most ARC samples, EPT taxa made up less than 40% of the total number of taxa (Figure 10). Stream invertebrate communities consisting of more than 50% EPT taxa were from high quality, hard-bottom, well-shaded sites in undeveloped catchments.

Figure 9.
Frequency distribution of numbers of EPT taxa recorded during the ARC freshwater invertebrate programme 2003-07.

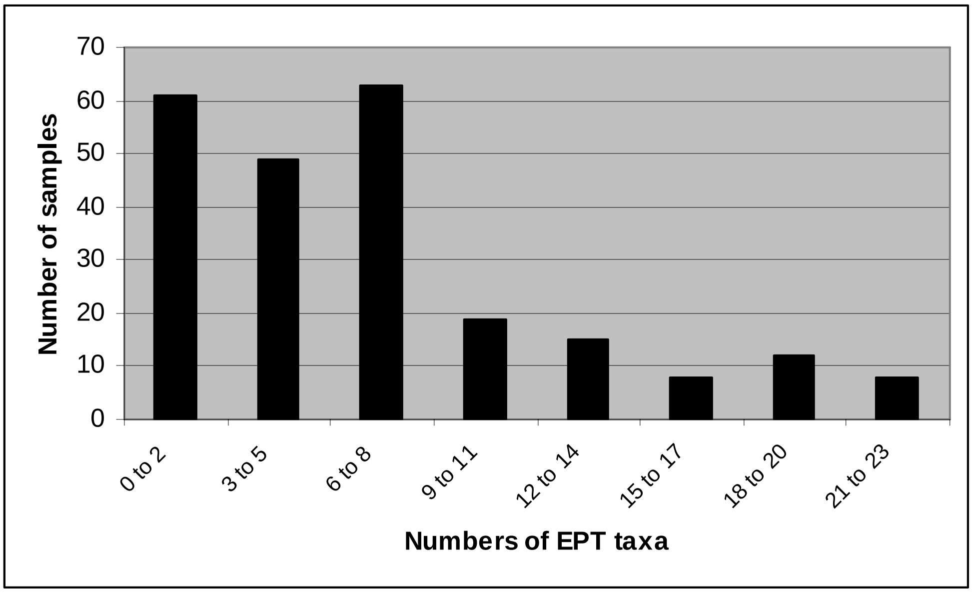
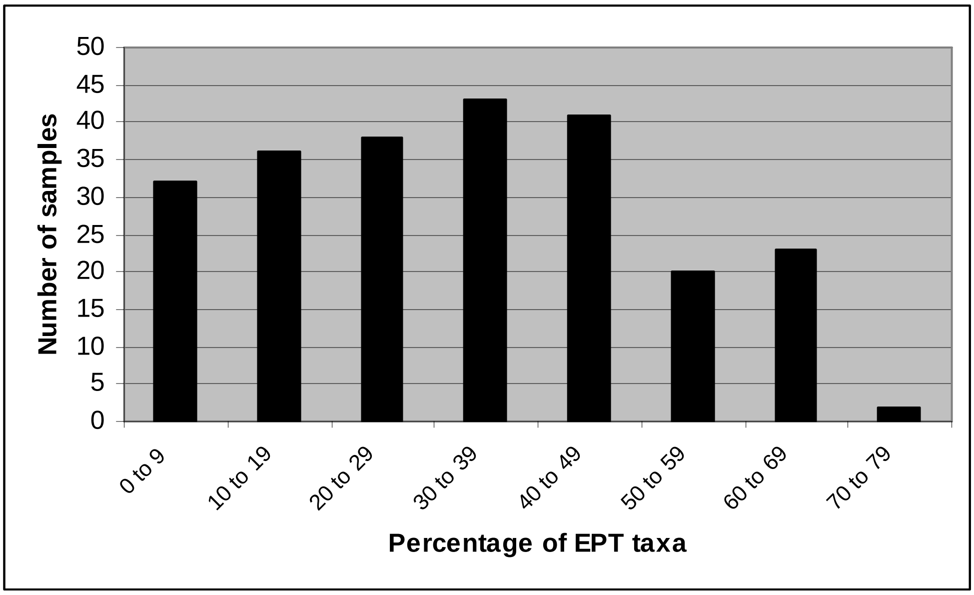


Figure 10.
Frequency distribution of percentage of EPT taxa (of the total taxa number) recorded during the ARC freshwater invertebrate programme 2003-07.



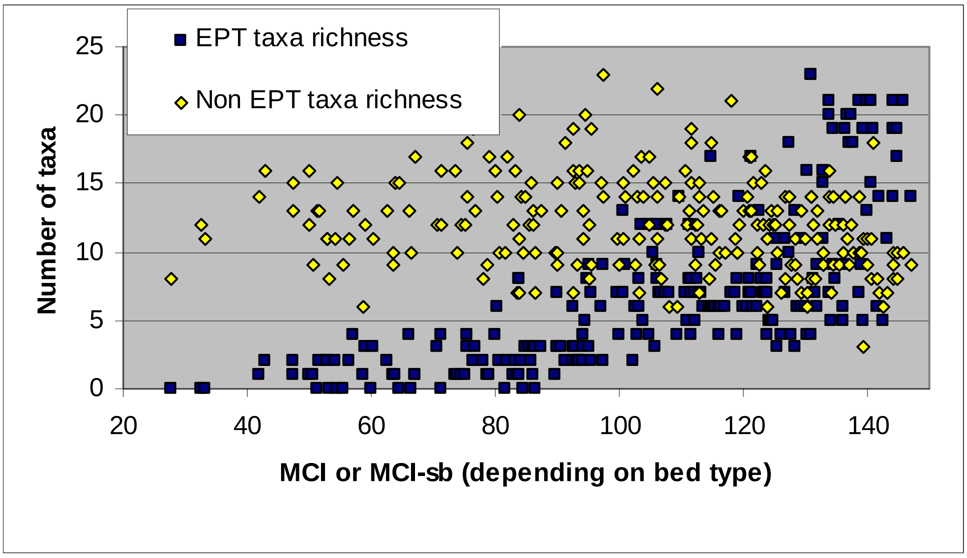
3.3 Relationships between community composition and biotic indices

3.3.1 Numbers of EPT taxa versus MCI or MCI-sb values

Biotic indices such as the MCI and MCI-sb are based on the sensitivities of different taxa to environmental stress. Sensitive taxa are assigned high tolerance values, and communities with a high proportion of such taxa typically produce high biotic index scores. Most EPT taxa are associated with good habitat and water quality and therefore they are among the high scoring taxa that increase MCI and MCI-sb values. Communities with high numbers (and proportions) of mayfly, stonefly and caddisfly taxa therefore tend to have high MCI and MCI-sb values (Figure 11). Invertebrate communities with MCI or MCI-sb values over 130 often include more EPT taxa than non-EPT taxa (Figure 11).

Figure 11.

Numbers of EPT taxa and non-EPT taxa versus MCI values (hard-bottom sites) or MCI-sb values (soft-bottom sites) recorded during the ARC freshwater invertebrate programme 2003-07.



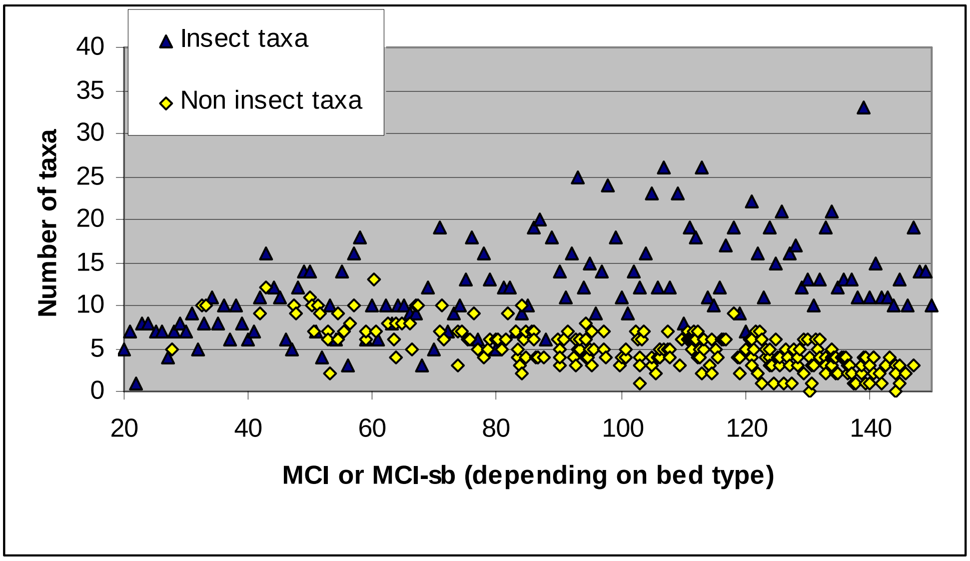
3.3.2 Numbers of insect taxa versus MCI or MCI-sb values

The EPT taxa are not the only high-scoring taxa in the MCI and MCI-sb indices. Tolerance values of above 7 have been assigned to other insect groups including hydraenid and ptilodctylid beetles, eriopterini craneflies, thaumaleid and blephariceridmidges, and dobsonflies (all found in the Auckland region). All non-insect taxa (crustaceans, molluscs, and worm-like groups) have tolerance values below 7, and most have scores below 5.

Non-insect taxa generally make up a larger proportion of invertebrate communities with low MCI or MCI-sb scores (e.g. scores below 80), and insect taxa dominate communities with high MCI or MCI-sb scores (e.g. scores above 100) (Figure 12).

Figure 12.

Numbers of insect taxa and non-insect taxa versus MCI values (hard-bottom sites) or MCI-sb values (soft-bottom sites) recorded during the ARC freshwater invertebrate programme 2003-07.



3.4 Relationships between biotic indices and bed hardness

High quality streams generally provide complex habitats with abundant stable refugia in the form of stony beds or woody debris. Complex, hard-bottom habitats provide a wide range of micro-habitat types that support high numbers of invertebrate taxa. It was found that hard-bottom sites support higher numbers of taxa than soft-bottom sites ($P<0.0001$). This pattern was particularly strong among the reference sites, but not at the urban sites (where many factors may limit numbers of taxa).

Most high scoring taxa, including most EPT taxa, are associated with hard-bottom habitats, and therefore most samples with high numbers of taxa (25 or more) and high MCI or MCI-sb values (over 120) are from hard-bottom sites (Figure 13).

High numbers of EPT taxa usually result in high total numbers of taxa (EPT taxa are part of the total taxonomic richness). High MCI-type indices can be produced by communities with low numbers of taxa as MCI-type indices are based on the proportion of sensitive taxa, not the numbers of sensitive taxa. The correlation between total numbers of taxa and numbers of EPT taxa (Figure 14) is therefore stronger than the correlation between numbers of taxa and MCI-type indices (Figure 13). 81% of the variation in total taxa amongst site means is associated with variation between numbers of EPT taxa, and this also incorporates nearly all the differences between land uses. On the same basis, only 34% of the variation between total taxa is associated with MCI indices.

The preference of many EPT taxa for hard-bottom sites is also strongly reflected in the plot between total numbers of taxa and numbers of EPT taxa (Figure 14). Most samples containing more than 20 taxa and more than 10 EPT taxa were from hard-bottom sites.

Figure 13.
MCI or MCI-sb values versus numbers of taxa recorded during the ARC freshwater invertebrate programme 2003-07.

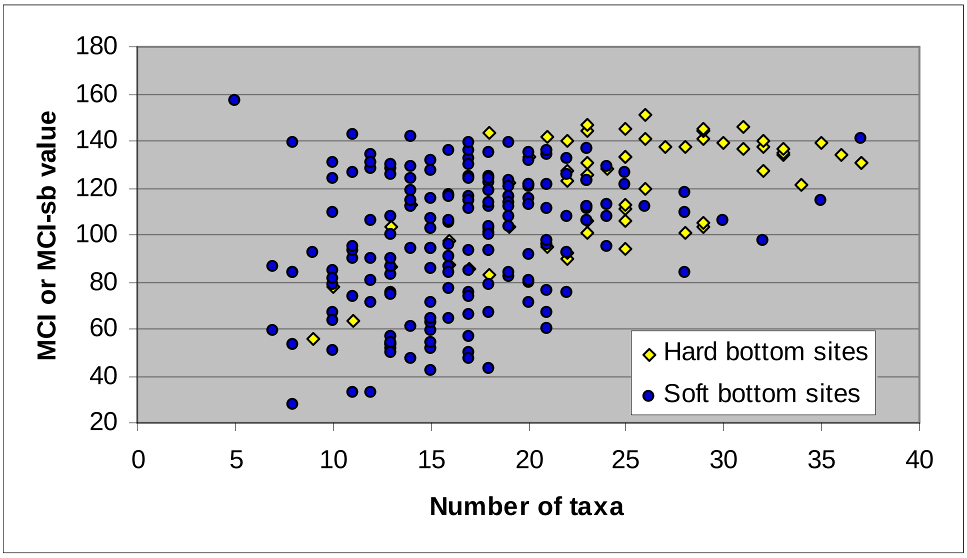
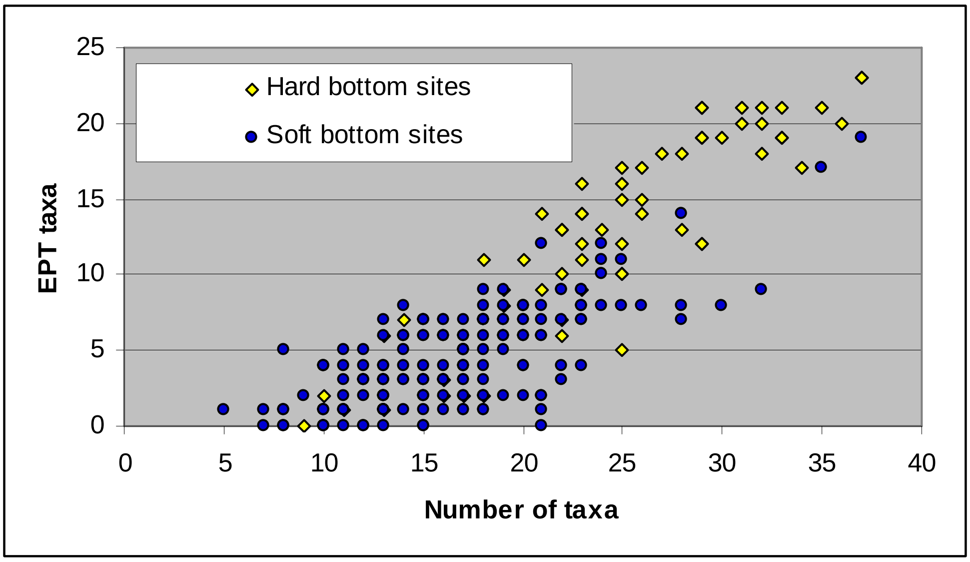


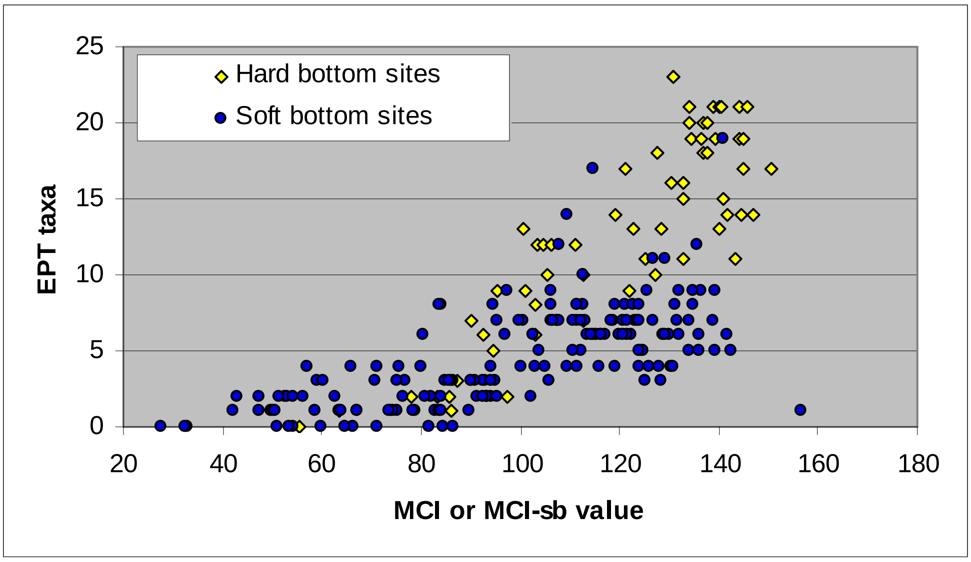
Figure 14.
Numbers of EPT taxa versus total numbers of taxa recorded during the ARC freshwater invertebrate programme 2003-07.



Given that many EPT taxa score highly in the MCI and MCI-sb indices, a positive correlation between numbers of EPT taxa and MCI related indices is to be expected (Figure 15). Most ARC samples containing more than 10 EPT taxa were hard-bottom sites with MCI values over 120 (Figure 15). Soft-bottom sites usually support fewer than 10 EPT taxa, even when the MCI-sb values are above 120.

Figure 15.

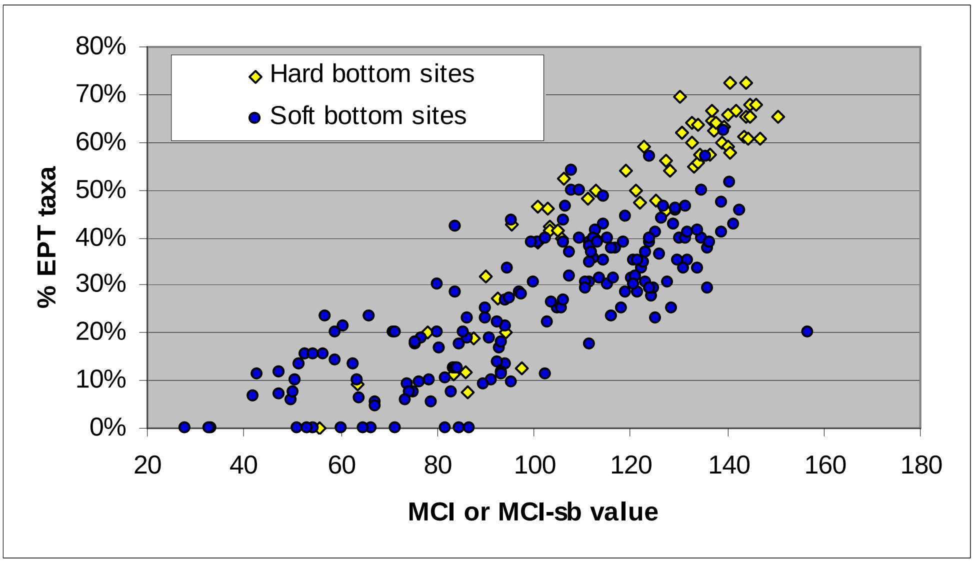
Numbers of EPT taxa versus MCI values (hard-bottom sites) or MCI-sb values (soft-bottom sites) recorded during the ARC freshwater invertebrate programme 2003-07.



The correlation between %EPT (numbers of EPT taxa expressed as a percentage of the total number of taxa) and MCI or MCI-sb is particularly strong; the regression slope being 0.75 (Figure 16). This is to be expected given that these indices are measuring similar aspects of community composition, i.e. the proportion of sensitive taxa (MCI and MCI-sb), and the proportion of EPT taxa (most of which are among the sensitive groups). In most samples where EPT taxa made up 50% or more of the community, the sample had been taken from a hard-bottom site and the MCI value was over 120.

Figure 16.

Percentage of EPT taxa (by taxa number) versus MCI values (hard-bottom sites) or MCI-sb values (soft-bottom sites) recorded during the ARC freshwater invertebrate programme 2003-07.



3.5 Relationships between biotic indices and ARC habitat scores

While streambed hardness can have a strong effect on invertebrate community composition, many habitat factors can also affect the suitability of a reach of stream for particular invertebrate taxa. During 2003 to 2007 the ARC applied a habitat quality assessment system incorporating scores for a range of habitat factors, to provide an overall score of habitat quality. Such scoring systems are designed to provide a more “holistic” assessment of habitat condition than simply recording one factor like bed composition.

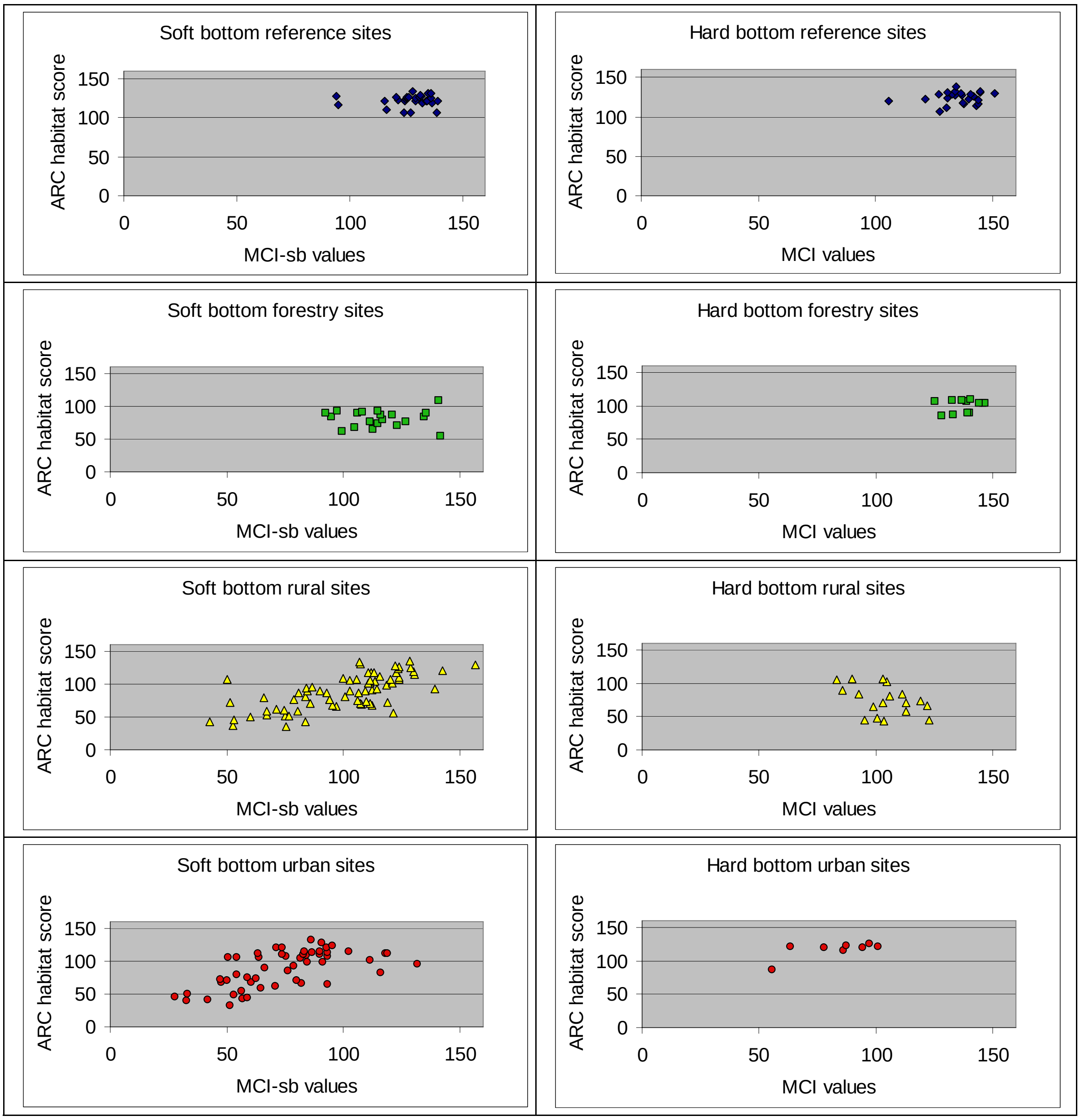
There is a positive correlation between ARC habitat scores and MCI-sb results ($p<0.0001$); the regression of habitat scores on MCI-sb has a slope of 0.61. The evidence for this comes mainly from soft bottom rural and urban sites because these provided a large dataset with a wide range of habitat scores (Figure 17).

The hard-bottom sites had slightly higher habitat scores and MCI values, but overall there was no strong evidence that the scores differ with bottom type (Figure 17).

Reference sites produced high habitat scores (on average 30 units higher than other land uses, with only one site below 100) and high MCI or MCI-sb values (similar to forest, but at least 40 units above urban and rural, with all sites over 100) in hard and soft bottom streams, hence the tightly clustered data points in Figure 17. Forestry sites had generally lower habitat scores, particularly at soft bottom sites (most habitat scores fell between 50 and 100), but there was no obvious correlation between habitat scores and biotic indices at these sites. Hard bottom sites in all land use groups showed limited variation in MCI values and habitat scores.

Soft bottom rural and urban sites produced a much wider range of biotic indices, and this data showed positive correlations between habitat scores and MCI scores (Figure 17).

Figure 17.
ARC habitat scores versus MCI values (hard-bottom sites) or MCI-sb values (soft-bottom sites) recorded from the four land use types during the ARC freshwater invertebrate programme 2003-07.



3.6 Effects of water quality on biotic indices

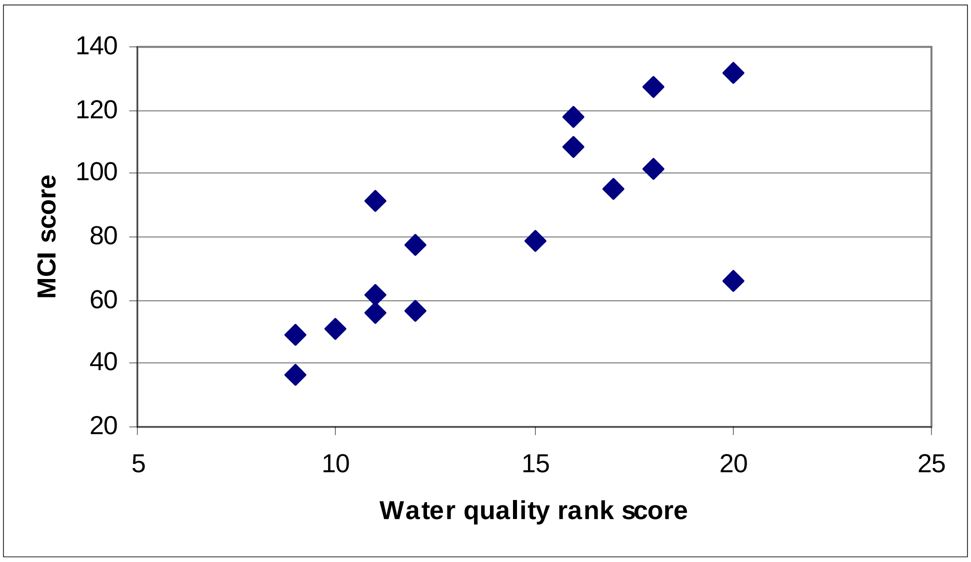
3.6.1 Long Term Baseline (LTB sites)

A state and trends analysis of the data from the rivers and streams water quality programme was recently undertaken (Scarsbrook, 2007). This analysis produced a ranking system for the water quality sites. This ranking was used to compare water quality and MCI indices at the 16 sites which are common to both programmes and had sufficient data available (Awanohi lower LTB was excluded from the water quality ranking exercise due to a short data record) (Figure 18). Whilst it is recognised that water quality is only one factor affecting invertebrate communities, the Spearman rank correlation between the water quality score and the MCI scores at the 16 sites was highly significant (R_s=0.81; P<0.001). However, this does not demonstrate a causative effect; this strong correlation may have arisen because the water quality and invertebrate community are responding to the same environmental stimuli.

A site of particular note in this correlation in Ngakaroa (lower right of Figure 18); the water quality rank score is high, whereas the MCI score is low compared with the other sites with a high water quality rank score. A possible explanation for this is the high levels of nitrate/nitrite observed at this site (Scarsbrook, 2007), however the low MCI may be primarily driven by factors other than water quality.

Figure 18

MCI scores versus water quality rank scores at the 16 sites common to both programmes.



3.7 Effects of land use on invertebrate communities

Land use strongly affects stream habitats and the condition of riparian vegetation, which in turn affects:

- levels of shade (and therefore stream temperatures)
- the supply of leaf litter, which starts most stream food webs
- the supply of woody debris (affecting habitat structure, complexity and stability)
- bank stability
- riparian habitat suitability for the terrestrial adult stages of many aquatic insects
- the volume and rate of contaminant and stormwater flows into streams

Streams covered by native forest (including "reference" sites) or exotic forest tend to have abundant shade, and an abundant supply of leaf litter and woody debris. The forest landscape allows infiltration of rainwater to shallow groundwater and this allows recharge of stream flows between rain events. Forested streams provide suitable stable habitat and water qualities for many sensitive invertebrate taxa, resulting in high MCI and MCI-sb values. Examples of sensitive EPT taxa found most frequently in native (reference) and exotic forest streams are shown in Figure 19.

Urban catchments with high proportions of impervious cover and man-made drainage networks often result in streams that rise rapidly (often with heavily polluted water) during rain events, and fall to unnaturally low flows during dry spells. Many studies have shown that the quality of the stream fauna declines as the percentage of impervious cover in a catchment reaches 10 to 20% (Suren, 2000; Morse *et al*., 2003).

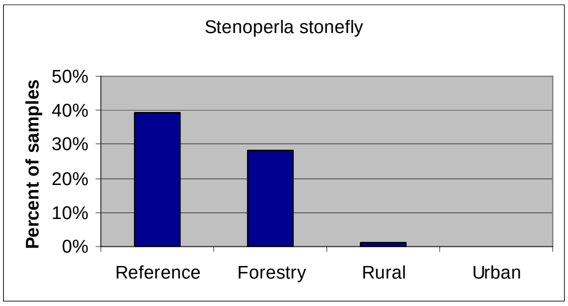
The most frequently occurring taxa in the ARC urban sites were pollution tolerant groups including *Potamopyrgus* and *Physella/Physa* snails, oligochaete worms, *Xanthocnemis* damselflies and *Paratya* shrimps. Two insect taxa known to tolerate low oxygen levels, *Chironomus* midges and *Xanthocnemis* damselflies were recorded more frequently in urban streams than in forestry, reference or rural streams (Figure 20).

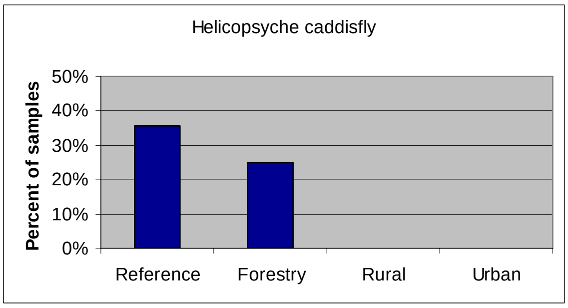
Allibone *et al*. (2001) found the predominant taxa in 64 Auckland urban stream sites were oligochaete worms, *Potamopyrgus*, *Gyraulus* and *Physa/Physella* snails, *Chironomus*, orthoclad and *Polypedilum* midges and the damselfly *Xanthocnemis*. EPT taxa richness was low at the 64 sites, and only the caddisfly *Triplectides* was relatively common in the survey.

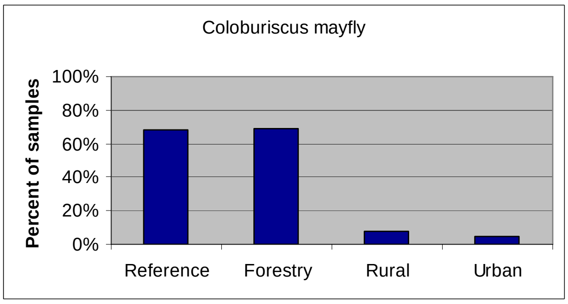
Rural catchments generally have low proportions of impervious cover, but they tend to have lower levels of shade, leaf litter or woody debris inputs than native or exotic forest streams. In addition, there are often diffuse nutrient inputs from agricultural activities and physical damage resulting from stock access. The habitat quality of rural streams is therefore typically intermediate between urban and forested streams, and this is reflected in the invertebrate faunas. The range of biotic index values from rural streams tends to fall between the ranges of forested and urban streams (Figures 21 and 22).

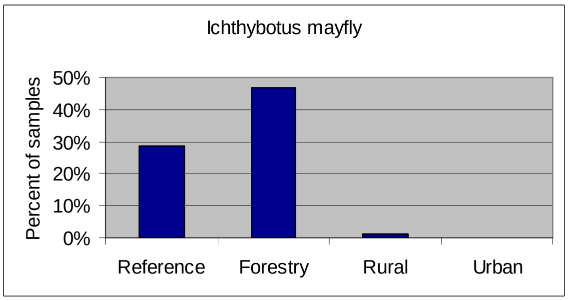
Figure 19.

The frequency of occurrence of selected freshwater invertebrate taxa that appear most suited to native or exotic forest streams (ARC freshwater invertebrate programme 2003-07 data).









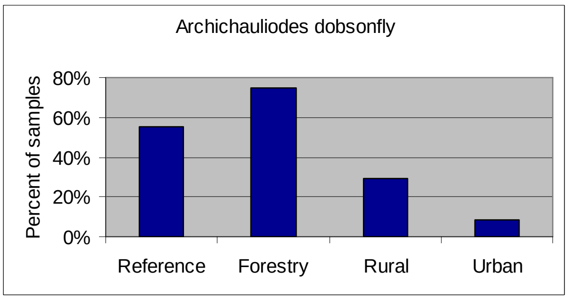
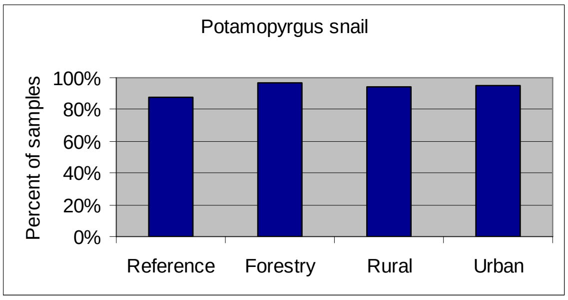
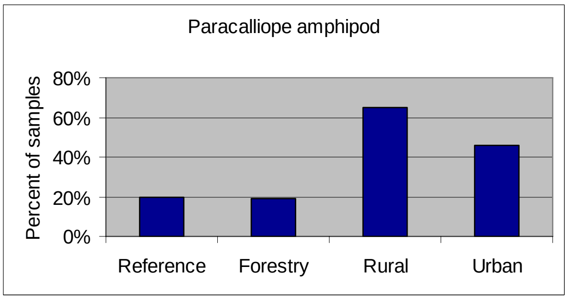
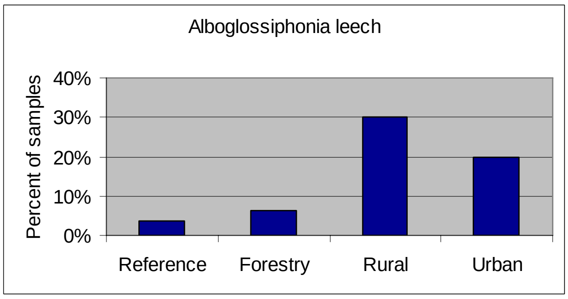


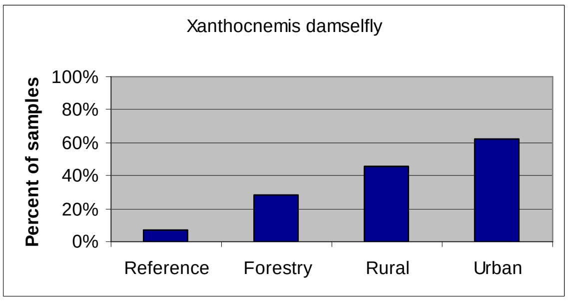
Figure 20.

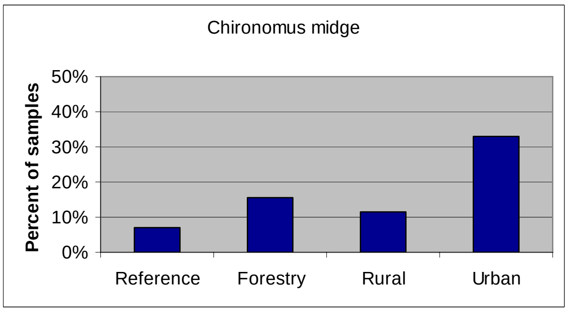
The frequency of occurrence of selected freshwater invertebrate taxa that thrive in unforested streams (ARC freshwater invertebrate programme 2003-07 data).







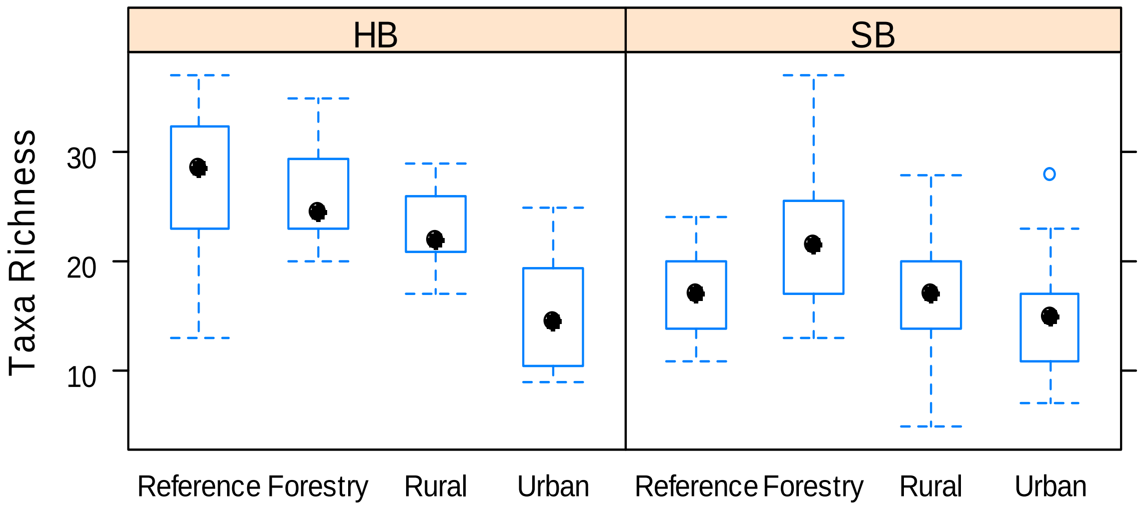




Taxonomic richness varied between land uses (P<0.0001), primarily reflecting the higher numbers of taxa at the reference and forestry sites compared with the urban and rural sites, but the trends were affected by bed hardness (Figure 21). Hard-bottom native forest (reference) streams supported the highest numbers of taxa (mean of 27.4) followed by exotic forest streams (mean of 25.6), rural streams (mean of 21.7) and urban streams (mean of 14.9). In soft-bottom streams, exotic forest sites supported the highest numbers of taxa (mean of 22.7) followed by reference and rural sites (both with a mean of 17.3) and urban sites (mean of 14.6). The 2001 survey of 64 Auckland urban stream sites (Allibone, 2001) recorded a mean of only 10 taxa.

Figure 21.

The numbers of taxa at hard-bottom (HB) and soft-bottom (SB) sites in different land use types during the ARC freshwater invertebrate programme 2003-07. HB reference n = 28, HB forestry n = 12, HB rural n = 13, HB urban n = 8, SB reference n = 28, SB forestry n = 20, SB rural n = 73, SB urban n = 53.

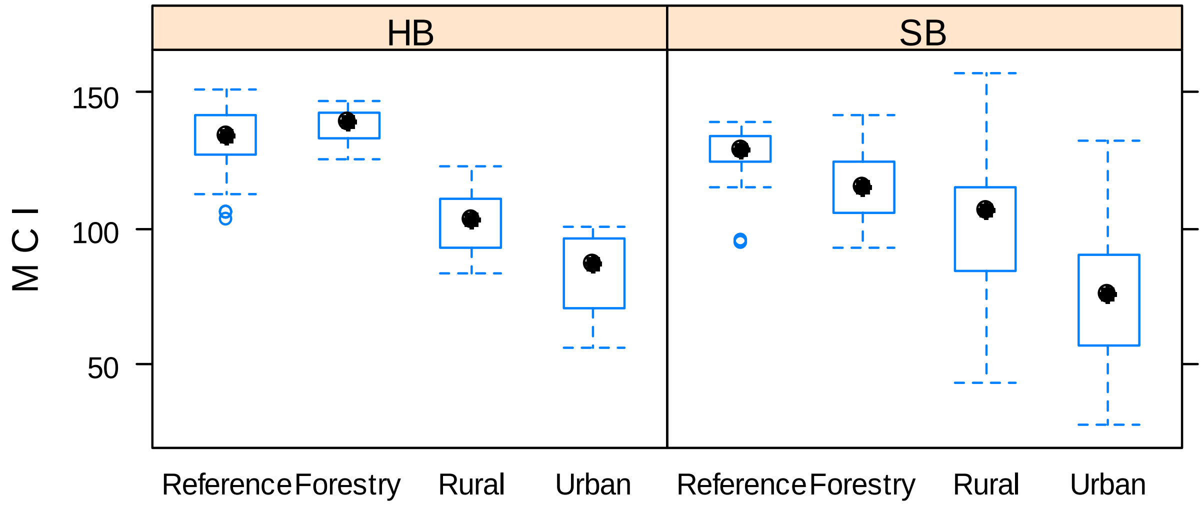


The effects of land use on the ranges of MCI and MCI-sb values are shown in Figure 22. There were significant differences between the index ranges of the different land uses (P<0.0001) primarily reflecting the high values from reference and forestry streams, intermediate values from rural streams and low values from urban streams. As expected, urban streams produced the lowest index values. Similar trends were found in a summary of ARC soft-bottom stream invertebrate data collected during 2000-2004 (Maxted, 2005), where native and exotic forest streams produced the highest index values and urban streams produced the lowest values.

The mean MCI values from ARC hard-bottom sites (2003-07 data) were 132.1 for reference streams, 127.1 for forestry streams, 100.0 for rural streams and 80.5 for urban streams. Allibone *et al.* (2001) recorded a very low mean MCI value of 64 in their survey of 64 Auckland urban stream sites. However, this study applied the hard-bottom MCI index to samples from soft-bottom streams as the MCI-sb was yet to be developed at this time.

Figure 22.

MCI values at hard-bottom (HB) sites, and MCI -sb values at soft-bottom (SB) sites in different land use types during the ARC freshwater invertebrate programme 2003-07. HB reference n = 28, HB forestry n = 12, HB rural n = 13, HB urban n = 8, SB reference n = 28, SB forestry n = 20, SB rural n = 73, SB urban n = 53.



The variability of index values in the ARC programme differed between land uses (P=0.023) with rural and urban index values being more variable, and forestry index values being least variable. The high proportion of soft bottom sites in the urban and rural areas contributes to the larger spread of index values.

There was no evidence of any difference between the MCI (hard-bottom) and MCI-sb (soft-bottom) mean values (P=0.15).

The effects of land use on stream invertebrates are also illustrated in plots of MCI and MCI-sb values versus numbers of taxa (Figures 23 and 24). All hard-bottom sites with 25 or more taxa and with MCI values over 120 were in areas of native forest (reference) or exotic forest. All sites with fewer than 25 taxa and with MCI values below 100 were in rural or urban areas (Figure 23).

Figure 23.
MCI values (hard-bottom sites) versus numbers of taxa with land use recorded during the ARC freshwater invertebrate programme 2003-07.

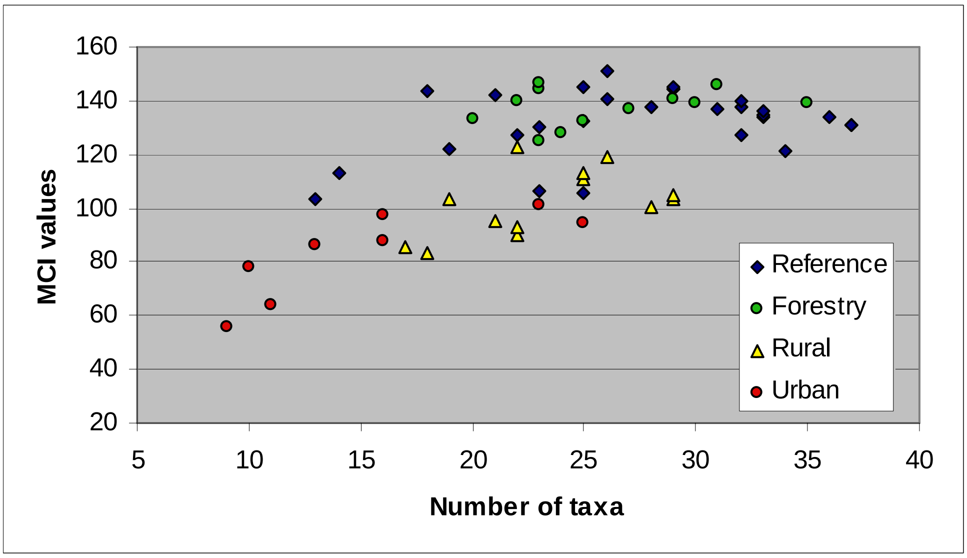
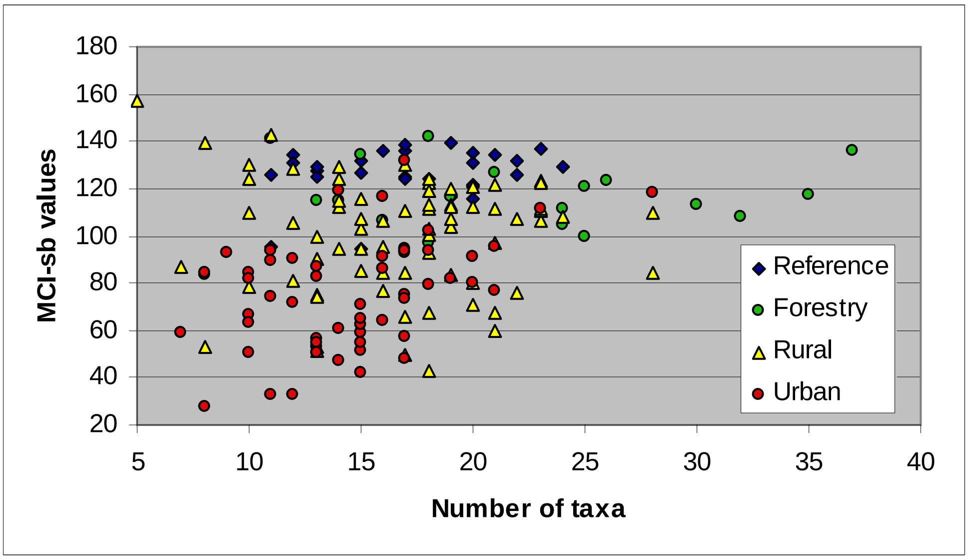


Figure 24.
MCI-sb values (soft-bottom sites) versus numbers of taxa with land use recorded during the ARC freshwater invertebrate programme 2003-07.



Most (64%) soft-bottom sites with MCI-sb values over 120 were from native or exotic forest streams, and most (86%) MCI-sb results below 120 were from rural or urban streams (Figure 24). Numbers of taxa varied greatly at soft-bottom sites in all land use areas; however most (93%) soft-bottom sites supporting fewer than 15 taxa were from urban or rural streams.

The effects of land use on stream invertebrate community composition are illustrated in a plot of numbers of EPT taxa versus numbers of taxa (Figure 25). Most (85%) sites with more than 20 taxa and more than 10 EPT taxa were from reference or forestry sites. Most (88%) urban sites supported fewer than 20 taxa and fewer than 5 EPT taxa.

Hard-bottom sites in reference and forestry streams show clear separation ($p<0.0001$) from hard-bottom rural and urban streams in the plot of MCI versus numbers of EPT taxa (Figure 26). Most hard bottom sites with MCI values over 120 and with more than 10 EPT taxa were from reference or forestry sites. Most (80%) hard bottom sites with MCI values below 120 and with fewer than 10 EPT taxa were from rural or urban sites.

The plot of MCI-sb versus numbers of EPT taxa shows greater overlap between the soft-bottom streams in native/exotic forest and the urban/rural areas (Figure 27). However, 50% of soft-bottom sites with MCI-sb values over 100 and with more than 5 EPT taxa were from reference or forestry sites, and most soft-bottom sites with MCI-sb values below 100 and with fewer than 5 EPT taxa were from rural or urban sites.

Figure 25.

Numbers of EPT taxa versus total numbers of taxa with land use recorded during the ARC freshwater invertebrate programme 2003-07.

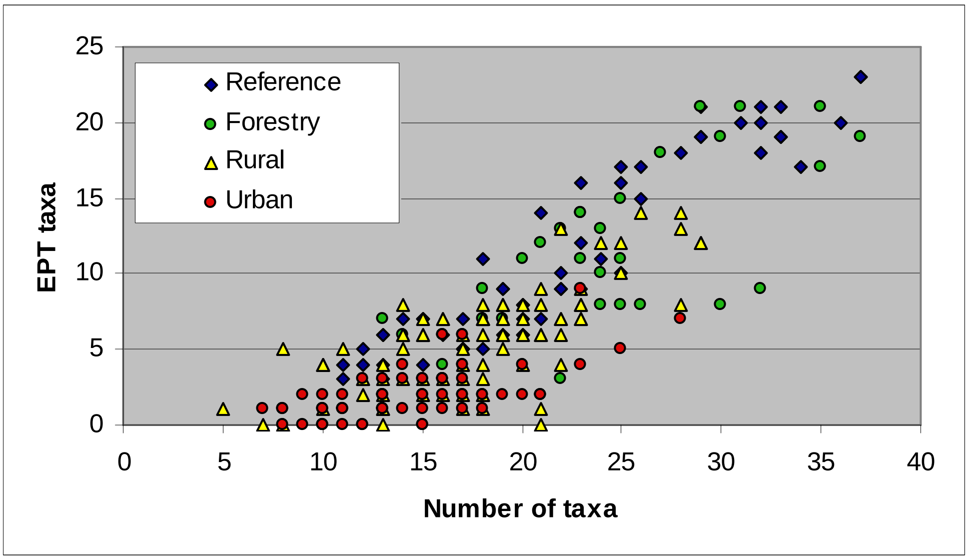


Figure 26.

MCI values (hard-bottom sites) versus numbers of EPT taxa with land use recorded during the ARC freshwater invertebrate programme 2003-07.

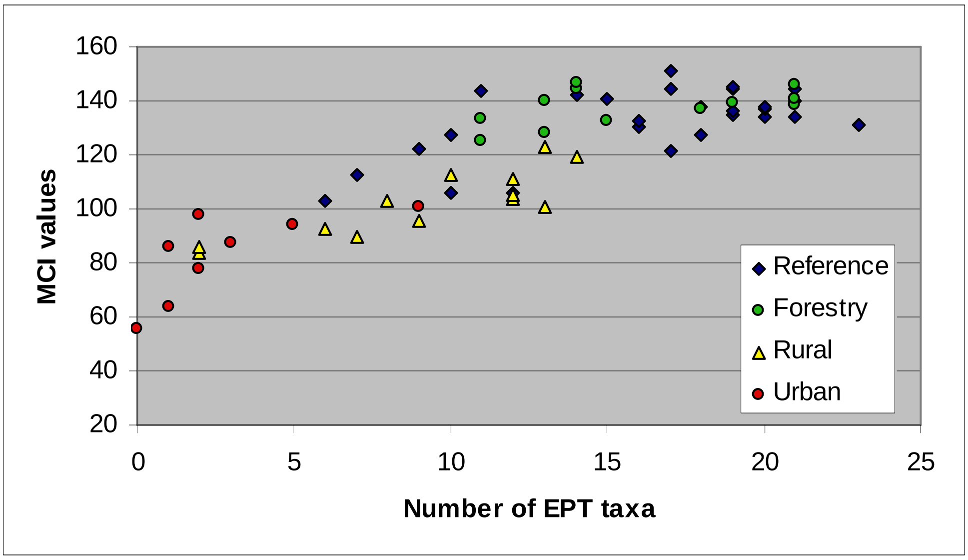
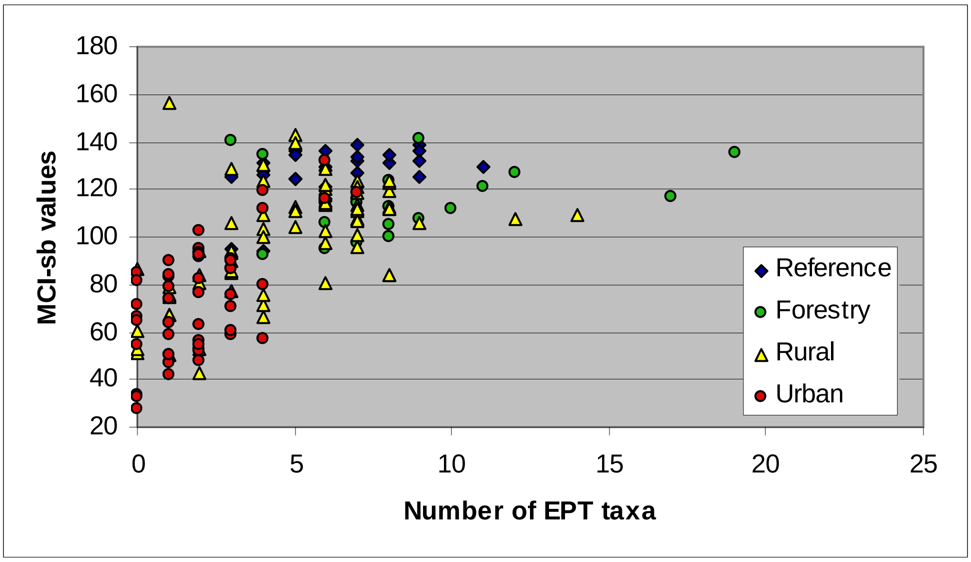


Figure 27.

MCI-sb values (soft-bottom sites) versus numbers of EPT taxa with land use recorded during the ARC freshwater invertebrate programme 2003-07.



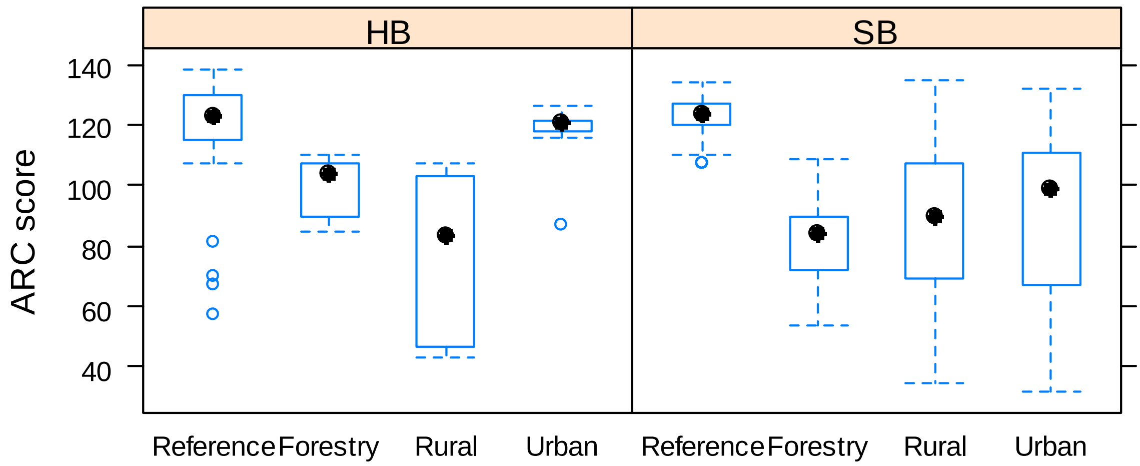
3.8 Relationships between land use and habitat quality

The ARC habitat quality assessment scores differed with land use (P<0.0001), with high values for the reference sites as expected. However, the habitat scores were not consistent with the differences in invertebrate populations between forestry, rural and urban sites (Figure 29). Urban habitats had higher average habitat scores than forestry or rural sites, in both hard-bottom and soft-bottom streams. This is inconsistent with the biological indicators, including taxonomic richness, numbers of EPT taxa, MCI and MCI-sb values, which all show that forestry and rural streams typically support more diverse and higher scoring invertebrate communities than urban stream habitats.

There was some evidence to suggest habitat scores differed between hard-bottom and soft-bottom sites (P=0.056) with soft-bottom scores typically 7 units lower. Variability in habitat scores differed between land uses (P=0.0007) with rural sites being the most variable.

Figure 29.

ARC habitat scores at hard-bottom (HB) and soft-bottom (SB) sites in different land use types during the ARC freshwater invertebrate programme 2003-07. HB reference n = 28, HB forestry n = 12, HB rural n = 13, HB urban n = 8, SB reference n = 28, SB forestry n = 20, SB rural n = 73, SB urban n = 53.



3.9 Comparisons between sampling sites

3.9.1 Numbers of taxa

The number of invertebrate taxa (taxonomic richness) collected in a stream sample provides information about the biodiversity and life supporting capacity of a stream reach. High numbers of taxa (e.g. over 30) are likely to reflect complex habitats (a range of stable microhabitats), and good water quality (cool temperatures, high dissolved oxygen and low pollutant levels). Low numbers of taxa often reflect unstable habitats (e.g. muddy beds or recent drying) or poor water quality.

Numbers of taxa vary between sampling dates at the same site as the populations of different taxa are affected by changes in flows, water quality (particularly temperatures and oxygen levels), biological changes (algal and macrophyte growths and riparian vegetation) and sampling variability. Therefore, comparisons between the taxonomic richness of different sites are ideally made using averages from several sampling occasions. In this review only sites with 3 or more year's data were used to produce an average number of taxa.

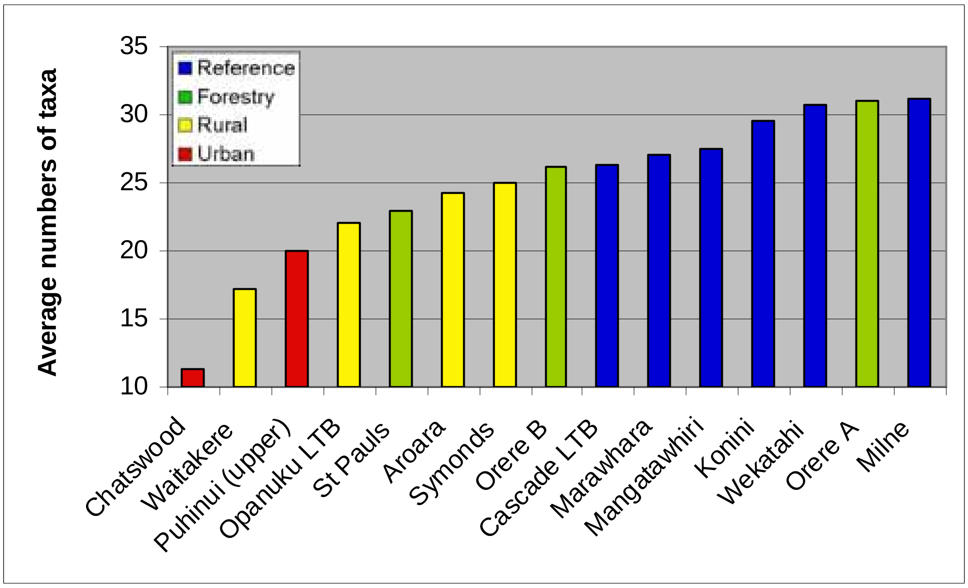
Hard-bottom samples tended to contain higher numbers of taxa than soft-bottom samples, and therefore it was considered that these groups of streams should be analysed separately (Figures 30 and 31).

Most samples from ARC hard-bottom sites contained more than 20 invertebrate taxa (Figure 30). The sites with highest average taxonomic richness in this ARC programme were located in native bush (Milne, Wekatahi, Konini, Mangatawhiri and Marawhara) or forestry areas (Orere A). On average these six sites supported 29 taxa, 18 of which were EPTs (primarily caddisflies and mayflies).

The five most frequently occurring taxa at these sites were:

- *Olinga* caddisflies, which feed on terrestrial leaf litter
- *Coloburiscus* mayflies, which filter fine organic particles drifting in bush covered streams
- *Deleatidium* mayflies, which graze fine organic films from stony beds in cold water streams
- *Archichauliodes* dobsonflies, which prey on other stream invertebrates
- *Stenoperla* stoneflies, which feed on stream invertebrates in cold water streams.

Figure 30.
Average numbers of taxa recorded at hard-bottom sampling sites sampled on at least 3 occasions in the ARC freshwater invertebrate programme 2003-07.

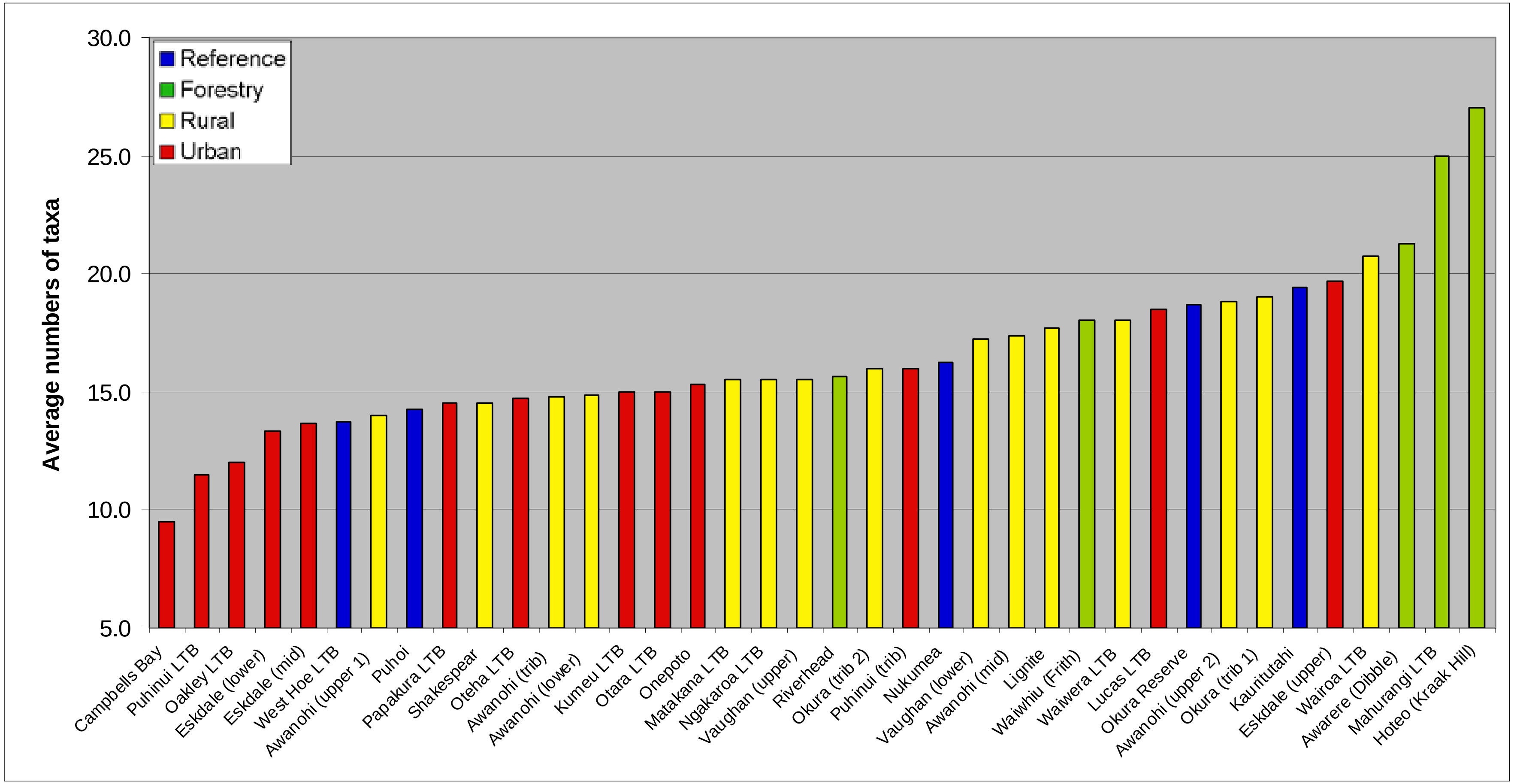


Most samples from ARC soft-bottom sites contained fewer than 20 invertebrate taxa (Figure 31). The soft-bottom sites with highest average taxonomic richness in this ARC programme were located in native bush (Kauritutahi), forestry areas (Hoteo @ Kraak, Mahurangi LTB and Awarere @ Dibble), a rural site (Wairoa), and an urban reserve site (Upper Eskdale). On average these six sites supported 22 taxa, including 8 EPTs, most of which were caddisflies and mayflies (stoneflies were rare). The five most frequently occurring taxa at these sites were:

- *Zephlebia* mayflies, which graze fine organic films, often on woody debris
- *Potamopyrgus* snails, which also graze fine organic films in slow flowing stream reaches
- *Polyplectropus* caddisflies, which filter drifting food particles in slow flowing reaches
- elmid beetles, which burrow into fine sediments and
- tanypod midges, which are predators common in slow flowing streams.

Figure 31.

Average numbers of taxa recorded at soft-bottom sampling sites sampled on at least 3 occasions in the ARC freshwater invertebrate programme 2003-07.



The sites with lowest average taxonomic richness in this programme were soft-bottom sites in urban areas (Campbells Bay, Puhinui LTB, Oakley LTB, and lower and mid Eskdale), and a reference site (West Hoe LTB) (Figure 31). Samples from these six sites contained an average of 12 taxa, including an average of only 1.7 EPT taxa (most commonly *Triplectides* caddisflies, occasionally *Zephlebia* mayflies and rarely any stonefly taxa). The five most frequently occurring taxa at these low taxonomic richness sites were:

- Physidae snails, which graze fine organic films and can tolerate highly polluted water
- *Potamopyrgus* snails, which also graze fine organic films in slow flowing stream reaches
- *Xanthocnemis* damselflies, which are pollution tolerant predators
- *Paratya* shrimps, which are found primarily in coastal reaches where streams tend to be most degraded
- oligochaete worms which may be the most pollution tolerant of all freshwater taxa.

3.9.2 MCI values (hard-bottom sites) and MCI-sb values (soft-bottom sites)

As with number of taxa, MCI indices from each sample were used to generate average MCI index values for sites where 3 or more years data were available.

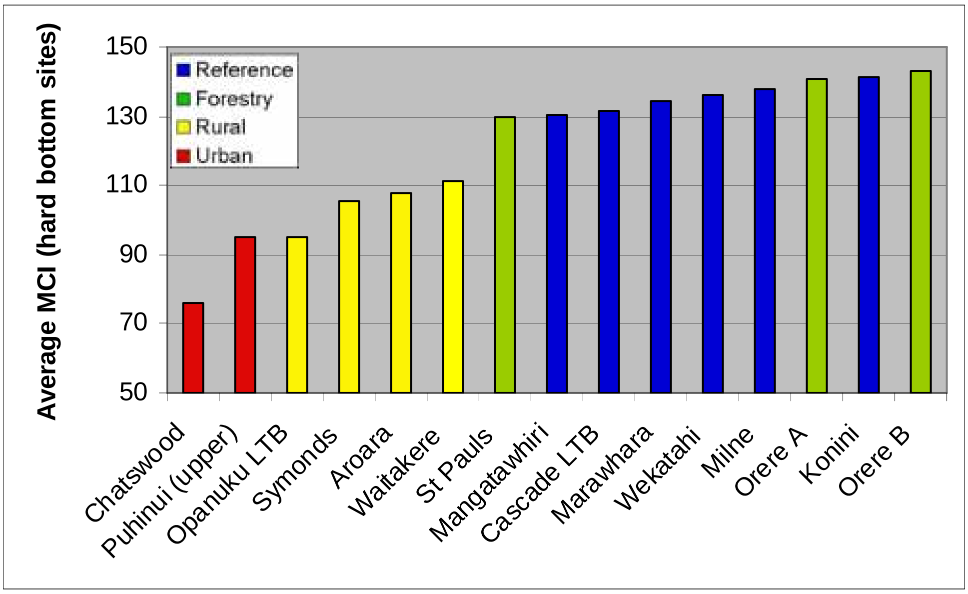
Most samples from ARC hard-bottom sites produced average MCI values over 120 (Figure 32). The sites with highest average MCI values in this programme were located in native bush catchments (Konini, Milne, Wekatahi and Marawhara) and exotic forestry areas (Orere A and B). The average MCI value from these six sites was 139, reflecting the high number of EPT taxa (average 18). These communities supported many invertebrates with taxa tolerance scores between 7 and 10 reflecting the high quality of these sites.

Most samples from ARC soft-bottom sites produced average MCI-sb values over 100 (Figure 33). The soft-bottom sites with highest average MCI-sb values in this ARC programme were located in native bush (Puhoi, Kauritutahi, West Hoe), forestry areas (Waiwhiu @ Frith) and rural areas with mixed native bush (upper Vaughan and upper Awanohi). The average MCI-sb value from these six soft-bottom sites was 129, reflecting a generally high proportion of sensitive taxa in these communities. These sites supported an average of 6 EPT taxa, usually consisting of mayflies and caddisflies (only occasionally stoneflies). The five most frequently occurring taxa at these sites were:

- *Zephlebia* mayflies, the most common EPT taxon in soft-bottom streams
- *Potamopyrgus* snails, which are abundant in most slow flowing streams
- *Polypedilum* midges, which are often abundant amongst woody debris
- *Paradixa* midges, which are often abundant in slow flowing streams
- *Polyplectropus* caddisflies, which often attach their filter feeding nets to woody debris in slow flowing streams.

Figure 32.

Average MCI values recorded at hard-bottom sampling sites sampled on at least 3 occasions in the ARC freshwater invertebrate programme 2003-07.

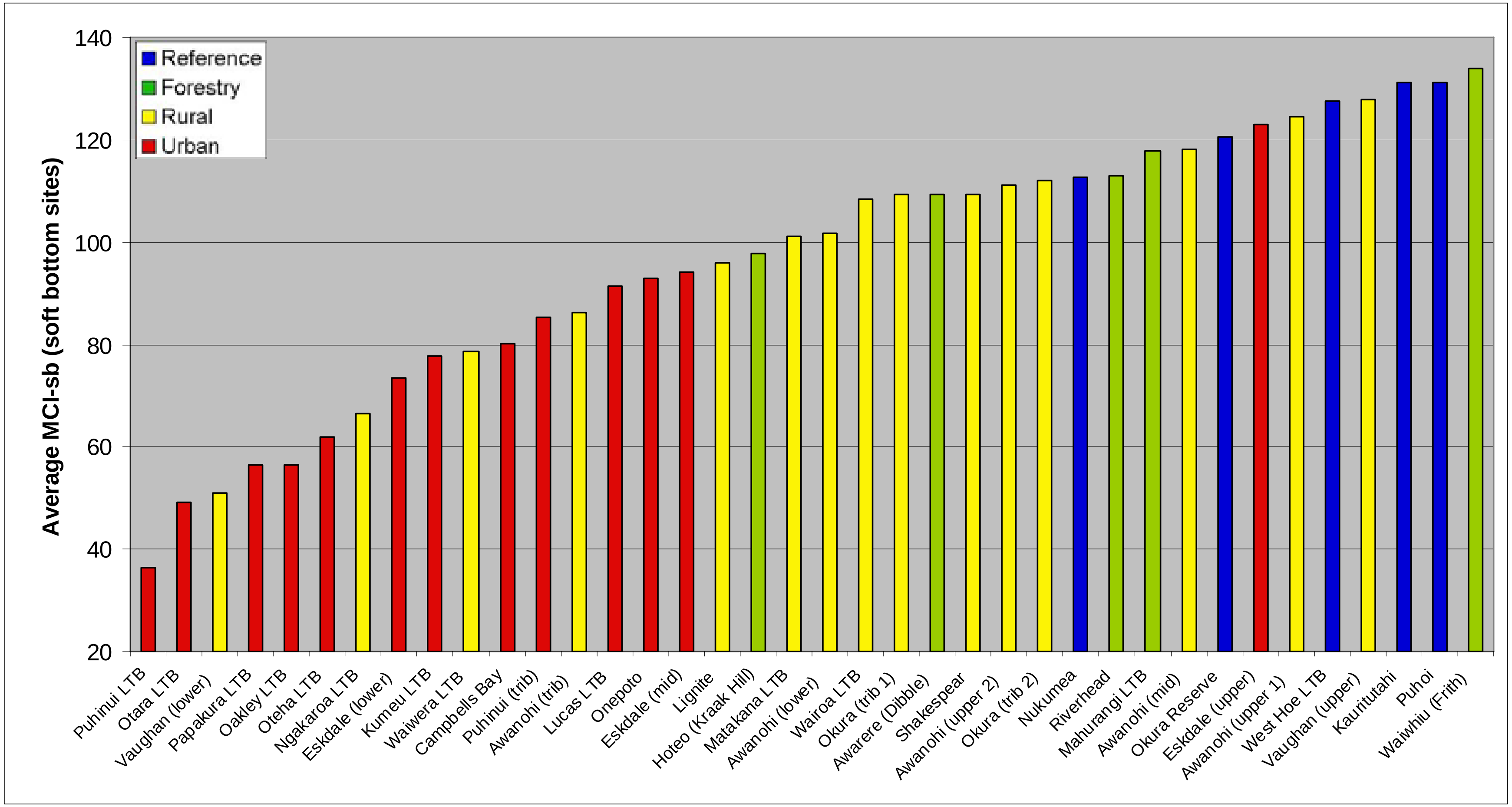


The sites with lowest average MCI or MCI-sb values in this programme (Figure 33) were soft-bottom sites in urban areas (Puhinui LTB, Otara LTB, Papakura LTB, Oakley LTB, Oteha LTB), and rural areas (lower Vaughan). The average MCI-sb from these sites was 52 reflecting a general lack of sensitive taxa in these communities.

The six sites with lowest MCI-sb values usually supported only one or two EPT taxa (usually *Oxyethira* or *Triplectides* caddisflies) and rarely any mayflies or stoneflies. The five most frequently occurring taxa at these low MC-sb sites were the same as the most frequently occurring taxa in the sites with lowest taxonomic richness, i.e. the tolerant Physidae and *Potamopyrgus* snails, *Xanthocnemis* damselflies, *Paratya* shrimps and Oligochaete worms. All of these groups have low MCI-sb taxa scores ranging from 0.1 (Physidae) to 3.8 (Oligochaetes).

Figure 33.

Average MCI-sb values recorded at soft-bottom sampling sites sampled on at least 3 occasions in the ARC freshwater invertebrate programme 2003-07



3.9.3 MCI quality classes

The average MCI value for sites with at least 3 years data available, were used to assign each of these sites to a quality class (Table 2) according to the published thresholds (Stark & Maxted, 2007b). Of the 53 sites with sufficient data, 17 were classified as excellent (MCI $\geq$ 120), 15 as good (MCI 100 to 119) 12 as fair (MCI 80 to 99) and 9 as poor (MCI < 80).

The geographical distribution of these sites is presented in Figure 34. It can clearly be seen that the majority of the fair and poor quality sites are contained within the Auckland metropolitan area.

Table 2.

Quality classes, based on average MCI scores, for sites with at least three years data.

Excellent quality		
FWM010 (Waiwhiu @ Frith)	FWM043 (Milne)	FWM050 (Wekatahi)
FWM012 (Puhoi)	FWM044 (Konini)	FWM057 (Awanohi upper 1)
FWM014 (Vaughan upper)	FWM045 (Mangatawhiri)	FWM065 (Kauritutahi)
FWM018 (St Pauls)	FWM046 (West Hoe LTB)	FWM073 (Eskdale upper)
FWM019 (Orere B)	FWM048 (Cascade LTB)	FWM075 (Okura Reserve)
FWM020 (Orere A)	FWM049 (Marawhara)	
Good quality		
FWM004 (Awarere Dibble)	FWM032 (Wairoa LTB)	FWM061 (Awanohi lower)
FWM008 (Riverhead)	FWM047 (Nukumea)	FWM062 (Okura trib 1)
FWM024 (Symonds)	FWM051 (Shakespear)	FWM063 (Okura trib 2)
FWM028 (Mahurangi LTB)	FWM058 (Awanohi upper 2)	FWM066 (Waitakere)
FWM031 (Matakana LTB)	FWM060 (Awanohi mid)	FWM068 (Aroara)
Fair		
FWM009 (Onepoto)	FWM022 (Hoteo Kraak Hill)	FWM064 (Campbells Bay)
FWM011 (Puhinui trib)	FWM034 (Opanuku LTB)	FWM070 (Lignite)
FWM015 (Puhinui upper)	FWM040 (Lucas LTB)	FWM072 (Eskdale mid)
FWM016 Chatswood	FWM059 (Awanohi trib)	FWM074 (Mauku Stream)
Poor		
FWM013 (Oteha LTB)	FWM035 (Oakley LTB)	FWM039 (Puhunui LTB)
FWM021 (Kumeu LTB)	FWM037 (Ngakaroa LTB)	FWM041 (Vaughan lower)
FWM033 (Papakura LTB)	FWM038 (Otara LTB)	FWM071 (Eskdale lower)

Figure 34
The distribution and quality class of sites with at least three years data.

4 Discussion

4.1 State and trends

The ARC freshwater ecology monitoring programme has provided a large database of the quality of Auckland streams based on the invertebrate community. Many samples have been collected from both hard-bottom and soft-bottom streams in catchments ranging from native forest to fully urbanised. To date, the information provided by the monitoring programme has provided a valuable assessment of the "state" of streams in Auckland. The invertebrate communities, and biological indexes based on these communities, are strongly correlated with the dominant land use in the catchment.

Analysis of this data has demonstrated that streams in native bush catchment typically support the highest quality invertebrate communities, with streams in urbanised catchments typically supporting the poorest quality invertebrate communities. The general pattern of biological quality followed a land use gradient from native forest (high) to exotic forestry to rural to urban (low); thus agreeing with the findings of Maxted (2005).

This quantification of the biological "state" of the regions streams as described by land use contributes to several of the SOE monitoring programme objectives as detailed in section 1.3. However, the length of the data record for this programme prevents a robust assessment of any change in the "state" over time. The consensus is that this type of "trends" analysis requires a data record of *ca.*10 years. For example, Environment Waikato reported trends in 2006 for their monitoring programme which commenced in 1994 (Collier & Kelly, 2006) and similarly Taranaki Regional Council reported a trends analysis in 2006 for their monitoring programme which commenced in 1995 (Stark & Fowles, 2006). Whilst the ARC programme has permitted an important assessment of state, the relatively short data record (maximum of 5 years) prevents a trends analysis at this stage. Nevertheless, it should recognised that the invertebrate data collected to date provides a comprehensive baseline with which to assess trends once an adequate data record duration is achieved.

4.2 Programme context

The findings of the state analysis of the freshwater ecology programme are very similar to the state analysis carried out for the ARC water quality monitoring programme. Scarsbrook (2007) undertook a state and trends analysis of the water quality programme and found that water quality issues are associated with intensive land uses, with sites in urban catchments typically having the poorer water quality than sites in forest or rural catchments. Given these two findings, it is perhaps not unexpected that there is strong correlation between water quality and biological quality at the 16 sites common to both programmes (Section 3.6). This does not indicate a causal relationship between stream water quality and biological quality; it is more probable that the results of the two monitoring programmes are a result of catchment land use and its effects.

When this monitoring programme is compared with analogous Regional Council or National monitoring programmes the results obtained are remarkably similar. Section 3.1.3 identified that the most frequently occurring taxa found in the ARC ecology programme were also among the most common taxa in the national monitoring network (NRWQN). Furthermore, taxa richness (section 3.2.1) and EPT richness (section 3.2.3) were similar to the ranges and medians of results found in the national and adjacent Regional Councils networks (Environment Waikato and Northland Regional Council). Whilst the ranges of the MCI scores obtained from these different monitoring networks were similar, the median value reported for the ARC programme was on average some 25 units higher. This MCI median may be high compared with the other datasets because of a greater proportion of monitoring sites in forested catchments in the ARC programme.

5 Recommendations

- The ARC's freshwater ecology monitoring programme has provided a valuable dataset for assessing the current state of invertebrate communities in a selection of the Region's streams. To maintain sample collection at these sites in order to obtain a dataset suitable for a robust trends analysis would greatly increase the value of the programme. Therefore it is recommended that the current annual monitoring is continued to build further upon the existing valuable database.
- In conjunction with the other ARC SoE monitoring programmes, the current site network should be reviewed to assess the regional representativeness of the current network. The benefits of aligning monitoring programmes to produce "super-sites", whereby ecological, water quality and hydrological information is measured at the same locations, should be investigated.
- In this report, we decided against using the "disturbance levels" employed in the previous summary of this programme to further investigate the effects of land use on streams (Maxted, 2005). These disturbance levels are useful interpretive tool for assessing land use, but the data used to generate these levels in the previous summary were based on land-use data from 2001. It was considered that this data is likely to be out-dated in assigning such fine levels of land use and the availability of up-to-date land use data should be explored for this purpose.
- The habitat quality assessment used in this monitoring programme was considered to provide little value in assessing the impact of land use on stream ecology (Section 3.5). Therefore, it is recommended that the Stream Ecological Valuation (SEV) (Rowe *et al.*, 2008) is implemented to assess the wider ecological functioning of the streams. The SEV incorporates a similar measure of habitat quality but is more detailed and holistic in its assessment.

6 Acknowledgements

Greg Arnold, Landcare Research, provided statistical analysis for this report.

This monitoring has benefited from the efforts of numerous ARC staff since its inception in 1999.

- John Maxted initiated the programme in 1999 and the current healthy state of the programme owes much to John's efforts.
- The following past or present ARC staff have all significantly contributed to the delivery of the programme and their efforts deserve to be recognised; Chris Hatton, Mike McMurtry, Marcus Cameron, Kylie Park, Grant Barnes, Joanne Yee, Colin McReady, Brent Evans.

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8 Appendix 1

The ARC habitat quality assessment field sheet

Habitat Parameter	Condition Category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
1. Aquatic Habitat Abundance	> 50% of channel favourable for epifaunal colonisation and fish cover; includes woody debris, undercut banks, root mats, rooted aquatic vegetation, cobble or other stable habitat. Also includes macrophyte dominated streams.	30-50% of channel contains stable habitat.	10-30% of channel contains stable habitat.	< 10% of channel contains stable habitat.
	20 19 18 17 16	15 14 13 12 1	10 9 8 7	5 4 3 2 1
2. Aquatic Habitat Diversity	Wide variety of stable aquatic habitat types present including: woody debris, riffles, undercut banks, root mats, rooted aquatic vegetation, cobble or other stable habitat.	Moderate variety of habitat types; 3-4 habitats present including woody debris.	Habitat diversity limited to 1-2 types; woody debris rare or may be smothered by sediment.	Stable habitats lacking or limited to macrophytes (a few macrophyte species scores lower than several).
	20 19 18 17 16	15 14 13 12 1	10 9 8 7	5 4 3 2 1
3. Hydrologic Heterogeneity	Mixture of hydrologic conditions i.e. pool, riffle, run, chute, waterfalls; variety of pool sizes and depths.	Moderate variety of hydrologic conditions; deep and shallow pools present (pool size relative to size of stream).	Limited variety of hydrologic conditions; deep pools absent (pool size relative to size of stream).	Uniform hydrologic conditions; uniform depth and velocity; pools absent (includes uniformly deep streams).
	20 19 18 17 16	15 14 13 12 1	10 9 8 7	5 4 3 2 1
4. Channel Alteration	Natural channel and meander pattern; no evidence of historic channel alteration e.g. dredging, channelisation stabilisation, or other human activity.	Natural channel. Minimal channel alteration. Channel shape and form may be influenced by recent sediment deposition.	Channelised. Channel form and shape unconstrained. Channel made of natural materials.	Channelised. Channel form and shape constrained by man made materials (e.g. culverts, gabions, concrete).
	20 19 18 17 16	15 14 13 12 1	10 9 8 7	5 4 3 2 1
5. Bank Stability (water level to bank full channel)	Stable: <5% bank effected; evidence of erosion or bank failure absent; minimal potential for future problems.	Moderately stable: 5-30% affected; areas of erosion mostly healed over; some potential for future problems.	Moderately unstable: 30-60% affected; high erosion potential during floods.	Unstable: 60-100% affected; eroded areas along runs and bends; bank sloughing and erosion scars common.
Left bank	10 9	8 7 6	5 4 3	2 1 0
Right bank	10 9	8 7 6	5 4 3	2 1 0
6. Channel Shade	>80% of water surface shaded. Full canopy.	60 - 80% of water surface shaded; mostly shaded with open patches.	20 - 60% of water surface shaded; mostly open with shaded patches.	<20% of water surface shaded. Fully open; lack of canopy cover.
	20 19 18 17 16	15 14 13 12 1	10 9 8 7	5 4 3 2 1
7. Riparian Vegetation Integrity (within 20 meters)	No direct human activity in the last 30 years; mature native tree canopy and intact native understory	Minimal human activity; mature native tree canopy or native scrub; understory shows some impact (e.g. weeds, feral animal grazing).	Extensive human activity affecting canopy and understory; trees exotic (pine, willow, poplar); understory native or exotic.	Extensive human activity; little or no canopy; managed vegetation (e.g. livestock grazing, mowed); permanent structures may be present (e.g. building, roads, carparks).
Left bank	10 9	8 7 6	5 4 3	2 1 0
Right bank	10 9	8 7 6	5 4 3	2 1 0

9 Appendix 2

Table of sites with MCI index score for each year of sampling.

Site ID	Site name	NZTM X	NZTM Y	Land use	substrate	2003	2004	2005	2006	2007
FWM004	Awarere (Dibble) ❑	1740623	5973867	forestry	soft	ns	99.7	121.0	104.9	111.5
FWM008	Riverhead ❑	1737125	5933216	forestry	soft	ns	ns	114.7	108.0	116.1
FWM009	Onepoto ❑	1754873	5925353	urban	soft	ns	ns	90.8	92.7	95.3
FWM010	Waiwhiu (Frith) ❑	1746500	5979619	forestry	soft	ns	123.3	135.6	134.7	141.6
FWM011	Puhinui (trib) ❑	1770102	5903276	urban	soft	ns	86.5	86.1	93.4	75.4
FWM012	Puhoi ❑ ❍	1744684	5960107	reference	soft	ns	136.0	127.8	126.9	134.2
FWM013	Oteha LTB ❑	1751903	5932876	urban	soft	ns	50.6	78.9	54.4	63.9
FWM014	Vaughan (upper) ❑ ❍	1754271	5938178	rural	soft	ns	128.9	130.0	130.4	121.6
FWM015	Puhinui (upper)	1770015	5903150	urban	hard	ns	100.9	87.5	97.5	94.4
FWM016	Chatswood ❑	1752860	5924026	urban	hard	ns	66.0	63.6	78.0	86.2
FWM018	St Pauls	1792352	5899343	forestry	hard	ns	125.2	128.3	133.0	132.8
FWM019	Orere B	1796917	5903677	forestry	hard	ns	139.3	140.7	147.0	144.3
FWM020	Orere A	1797276	5903177	forestry	hard	ns	137.0	145.8	134.1	138.9
FWM021	Kumeu LTB ❑	1739216	5928819	urban	soft	ns	93.3	81.9	70.8	64.7
FWM022	Hoteo (Kraak Hill) ❑	1743264	5974291	forestry	soft	ns	94.8	97.3	106.3	92.5
FWM023	Botany	1770333	5913019	urban	hard	ns	55.6	ns	ns	ns
FWM024	Symonds	1775578	5893744	rural	hard	ns	122.7	103.4	95.2	100.7
FWM028	Mahurangi LTB ❑	1747649	5964864	forestry	soft	ns	112.8	126.6	117.0	114.7
FWM031	Matakana LTB ❑	1753615	5976422	rural	soft	ns	100.7	114.4	95.5	94.3
FWM032	Wairoa LTB ❑	1782680	5901828	rural	soft	ns	112.3	107.8	107.5	106.2
FWM033	Papakura LTB ❑	1771066	5900274	urban	soft	ns	56.5	56.9	59.1	52.9
FWM034	Opanuku LTB	1742087	5915597	rural	hard	ns	103.2	90.0	83.3	104.8
FWM035	Oakley LTB ❑	1751914	5917503	urban	soft	ns	50.2	62.5	54.3	58.9
FWM036	Waiwera LTB ❑	1748575	5953652	rural	soft	ns	80.3	ns	ns	76.9
FWM037	Ngakaroa LTB ❑	1775165	5881618	rural	soft	ns	52.8	75.6	83.8	53.3
FWM038	Otara LTB ❑	1768326	5908371	urban	soft	ns	42.0	60.4	47.3	47.5
FWM039	Puhinui LTB ❑	1766445	5904298	urban	soft	ns	27.8	33.1	51.6	32.7
FWM040	Lucas LTB ❑	1751795	5934561	urban	soft	ns	116.3	80.0	93.4	76.4
FWM041	Vaughan (lower) LTB ❑ ❍	1755414	5938729	rural	soft	ns	42.9	60.1	51.2	50.0
FWM043	Milne ❍	1793286	5890536	reference	hard	ns	140.8	144.1	130.8	136.4

FWM044	Konini ❍	1795198	5895283	reference	hard	ns	150.8	137.5	137.9	140.0
FWM045	Mangatawhiri ❍	1793923	5897394	reference	hard	ns	141.9	127.5	130.4	121.2
FWM046	West Hoe LTB ❑ ❍ ♦	1748304	5950603	reference	soft	134.1	131.0	125.4	129.4	124.8
FWM047	Nukumea ❑ ❍	1749411	5951400	reference	soft	ns	131.6	129.3	94.3	95.1
FWM048	Cascade LTB ❍	1735633	5916371	reference	hard	ns	144.8	144.8	103.3	105.6
FWM049	Marawhara ❍	1730774	5910762	reference	hard	ns	143.3	130.8	127.3	136.8
FWM050	Wekatahi ❍	1731543	5910437	reference	hard	ns	144.1	133.9	132.8	133.9
FWM051	Shakespear ❑ ❍	1763934	5946824	rural	soft	ns	113.2	122.2	86.6	115.5
FWM052	Otanerua ❑	1749829	5952217	reference	soft	ns	120.7	125.5	ns	ns
FWM056	Mt Auckland ❑ ❍	1730852	5964294	reference	soft	ns	ns	131.3	ns	136.1
FWM057	Awanohi (upper 1) ❑ ♦	1750102	5936833	rural	soft	128.5	142.5	156.8	139.3	124.0
FWM058	Awanohi (upper 2) ❑ ♦	1750516	5937690	rural	soft	113.5	106.4	120.9	103.0	111.4
FWM059	Awanohi (trib) ❑ ♦	1750523	5937708	rural	soft	84.3	78.6	90.2	92.9	84.7
FWM060	Awanohi (mid) ❑ ♦	1750627	5937720	rural	soft	124.0	123.9	122.8	120.1	100.0
FWM061	Awanohi (lower) LTB ❑ ♦	1751424	5938711	rural	soft	109.4	80.7	110.8	94.3	112.5
FWM062	Okura (trib 1) ❑ ♦	1754059	5939002	rural	soft	107.4	106.8	110.7	ns	112.1
FWM063	Okura (trib 2) ❑ ♦	1752669	5938790	rural	soft	111.7	118.7	117.2	ns	105.8
FWM064	Campbells Bay ❑	1757043	5931334	urban	soft	ns	81.6	83.5	71.3	84.0
FWM065	Kauritutahi ❑	1741899	5893226	reference	soft	ns	133.9	132.1	126.2	134.8
FWM066	Waitakere	1733630	5918805	rural	hard	ns	112.9	106.1	122.1	103.1
FWM068	Aroara	1789897	5903472	rural	hard	ns	119.2	111.2	92.7	112.8
FWM069	Duder	1785588	5913500	rural	soft	ns	ns	ns	75.2	74.5
FWM070	Lignite ❑	1752340	5929258	rural	soft	ns	ns	111.6	84.6	91.3
FWM071	Eskdale (lower) ❑	1752441	5926765	urban	soft	ns	ns	63.4	82.9	73.6
FWM072	Eskdale (mid) ❑	1752739	5926517	urban	soft	ns	ns	102.3	89.8	90.0
FWM073	Eskdale (upper) ❑	1752993	5926470	urban	soft	ns	ns	85.6	71.2	119.1
FWM074	Mauku stream (STP) ❑	1760162	5882718	rural	soft	ns	ns	85.6	71.2	97.1
FWM075	Okura Reserve ❑	1753241	5940408	reference	soft	ns	ns	121.4	124.1	116.4
FWM076	Duck Creek ❑	1752605	5970451	rural	soft	ns	ns	67.1	ns	67.1
FWM078	Waiwhiu (Waiwhiu) ❑	1748405	5977107	reference	soft	ns	ns	142.1	ns	ns
FWM080	Ararimu	1734910	5932518	rural	soft	ns	ns	ns	ns	103.8
FWM081	Mauku (Aka Aka)	1764275	5877040	rural	soft	ns	ns	ns	ns	66.0
FWM084	Motutapu	1771846	5929049	rural	hard	ns	ns	ns	ns	85.9
FWM086	Kaukapakapa	1730776	5945155	reference	soft	ns	ns	ns	ns	138.8
FWM087	Dyers Creek (bush)	1751076	5963704	rural	Soft	ns	ns	ns	ns	123.4
FWM088	Dyers Creek (paddock)	1750910	5963846	rural	soft	ns	ns	ns	ns	111.7